Development and Evaluation of Sustainable Woven Fabric Produced from Recycled Cotton and Hemp

By

GLORY GRACE PRASAD

(20PBX003)

A Thesis submitted to the

Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore -641043

In Partial Fulfilment of the Requirement for the Degree of Master of Science in

BIO-TEXTILES

MAY 2022

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Certified as Bonafide Research Work

Signature of the Head of the Department 30/5/22

Signature of the Supervisor

DECLARATION

I declare that the dissertation entitled **"Development and Evaluation of Sustainable Woven Fabric Produced from Recycled Cotton and Hemp"** submitted by me for the degree of Master of science (M.Sc.,) is the record of work carried out by me during the period from 2021 to 2022 under the guidance of **Dr. (Mrs.) R. PRABHA,** M.Sc., Ph.D., SLET., **Assistant Professor** of Department of Textiles and Clothing, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore-641043 and has not formed the basis for the award of any Degree, Diploma, Associate ship, Fellowship, Titles in this University or any other similar institution of higher learning.

Prasad.

Signature of the Candidate

CERTIFICATE FROM THE SUPERVISOR

I certify that dissertation entitled **"Development and Evaluation of Sustainable Woven Fabric Produced from Recycled Cotton and Hemp"** submitted for the degree of Master of science (M.Sc.,) Bio-Textiles by Glory Grace Prasad is the record of project work carried out by her during the academic year 2021 to 2022 under my guidance and supervision and this work has not formed the basis for the award of any Degree, Diploma, Associate ship, Fellowship. Titles in this University or any other similar institution of higher learning.

30/5/22

Signature of the HOD

Signature of the Supervisor with Designation

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ACKNOWLEDGMENT

"They will speak of the glorious splendor of your majesty, and I will meditate on your wonderful works"

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GLORY GRACE PRASAD

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INTRODUCTION

1. INTRODUCTION

The textile and apparel industry is one of the most ancient and well-known industries. The textile industry is well-known for being a significant contributor to the national economy. It occupies a unique position in terms of economic development because it employs approximately 35 million people. It is one of the oldest industries with an unrivalled reputation. The industry is intertwined with other industries such as agriculture and rural sectors. Textile production accounts for 14 percent of total economy, and it also accounts for 14 percent of industrial production (Shakya and Swami, 2021).

The Indian textile industry is one of the largest in the world, involving massive amounts of raw materials, a variety of fabric construction methods, and the production of clothing and other items. It generates 8 percent of overall excise revenue and accounts for 3% of the country's GDP. The textile industry employs approximately 60 million people indirectly (agriculture of cotton and other natural fibers) and directly employs 21 percent of the workforce (Dhanabhakyam, 2007). The structure of textile and apparel industry is quite sophisticated, with products and processes ranging from simply woven fabrics to special finished technical textiles to advanced textile operations. The Indian textile industry has diversified from manufacturing traditional items to fashion items for international markets (Chavan, 2001).

Textile and fashion is one of the most diverse industries. The industry is linked to a variety of other industries of various sizes around the world, and it incorporates procedures such as design, construction, marketing, and quality testing. The textile industry is large and capable of producing millions of tones of textiles each year. It is, nevertheless, one of the world's most unsustainable industries, in terms of the environment as well as in terms of social concerns. It is the second most polluting business on the global scale, after the chemical industry. It accounts for roughly 10% of total global emissions and produces 15-35 tones of CO_2 every tone of textiles (European Parliament 2020; Ardbo and Ekvall, 2021).

In recent years there has been an increase in advanced technologies, industrialization, and the everyday changing scenarios in fashion has resulted in need and desire for enormous textile production. Although the textile industry is one of the most important consumer goods industries, any type of textile production, whether it's fabric construction or pre- or post-treatment, produces pollutants and waste in some way. Textile waste in landfills is currently a source of concern, with a wide range of textile waste processing options available. The textile waste generation does not cease with production but also extends to pre and post consumer waste depending on consumption. The demand for appropriate textile waste management has risen as a result of increased awareness about the excessive damage to the environment and health (Shakya and Swami, 2021).

The growing awareness of the environmental damage caused by synthetic materials has contributed to the creation of eco-friendly materials. Researchers have shown a strong interest in producing such materials that can replace synthetic materials (Thyavihalli, 2019). Nowadays, people's living standards are rising, and the need for new and innovative textiles with higher quality has become urgent. Today laymen have been educated on how every decision they make and product they purchase has a decisive repercussion on the earth's surface. As a result, the requirements for textiles and clothing today is not only about durability and style, but also about improving one's lifestyle with products that have little or no detrimental impact on the biosphere of Earth (Erdumlu and Ozipek, 2008).

Sustainability refers to meeting human needs without overwhelming environment or society (Gardetti and Muthu, 2015). To enhance this, organic textiles must encompass raw material cultivation, mass production, manufacturing, processing, packing, labelling, and worldwide distribution. The growing demand for healthier and more sustainable textile products, the textile industry has lead to significant investments in research and development to find solutions for many existing crises, such as finding alternatives to conventional fibres and methods to recycle, reuse and repurpose (Patti et al., 2020).

Textile industries all over the world must make an effort to recycle the waste that they generate. A well-organized post-consumer recycling system can both benefit the environment and save money. With the advancement of the textile industry and ongoing efforts to find ways to implement sustainability, the practise of reclaiming fibres from textile waste has become much easier. It also avoids the intensive process of producing textiles from virgin fibres, which involves the use of excessive energy and pollutants that are required to produce textiles. Textile recycling and reuse are few of the issues that must be addressed on a regular basis in both the manufacturing and consumer sectors of the industry (Lau, 2015).

Fashion should go hand in hand with biodegradable, sustainable, and recycled clothing. The fashion industry generates a significant amount of waste, carbon emissions, pollution, water consumption and energy consumption (Lu and Hamouda, 2014). Textile waste can be converted into novel and functional products using either up-cycling or recycling techniques. While the practise of recovering and reusing textiles is a good solution, it can only address a fraction of the damage caused to the environment and society by the manufacturing process and consumption (Shakya and Swami, 2021).

Textile waste materials can be categorized into three categories: (i) pre-consumer textile wastes, (ii) post-industrial textile wastes and (iii) post-consumer textile wastes. Pre-consumer textile wastes are wastes that never reach consumers and are sourced straight from the original producers. Ginning wastes, opening wastes, carding wastes, comber noils, fabric cutting wastes, fabric wet processing wastes, and apparel manufacturing wastes are few of the examples. Post-industrial textile wastes are formed during the production of upstream goods. These mostly come from raw fibre producers, tyre cord makers, polymerization factories, and other plastic product manufacturers. Post-consumer textile wastes are wastes generated by consumers, and they are often clothing that are ready for disposal or landfill (Muthu, 2017).

Recycling is a deliberate waste disposal effort that converts waste into new materials. It involves breaking down fabric scraps into new materials in order to create new fibres. Recycled or up-cycled cotton is a more environmentally friendly clothing fabric that performs just as well as organic cotton. It reduces the amount of textile waste produced by conventional cotton production. Recycled cotton is an eco-friendly fabric substitute for traditional cotton, better cotton, and organic cotton. This fibre is made of cellulose, which is used in the global clothing industry to make apparel, footwear, and accessories. Recycled cotton is a natural material composed of cellulose fibres derived from renewable resources, cotton waste derived from second-hand clothing, textile waste, or cotton production leftovers (Kellock, 2014).

Cotton is the foundation of the global textile trade. Cotton is used in many of our everyday textile materials because it is durable and can be woven and colored in an unlimited number of ways. Cotton, like the other plant fibres, is mostly composed of cellulose. Cotton has for long commanded the textile market and is renowned as the "King" of fibres (Pant et al., 2004). Cotton is the finest type of cellulose found in nature, outperforming any other vegetable fibre in terms of physical and chemical homogeneity (Gopalakrishnan and Aravindhan, 2005). Cotton fibres are hollow, natural fibres that are soft, cool, breathable, and absorbent. They are durable, dye absorbing, and resistant to abrasion and high temperatures. Cotton in a word is relaxing (Ravandi and Valizadeh, 2011).

Hemp has an extensive root system that prevents soil erosion, removes toxins, serves as a disease protective layer, and aerates the soil for future crops. Hemp fibre, derived from the hemp plant, is a fine, light-colored, lustrous, and strong bast fibre. The bark of the hemp stalk contains bast fibres, which are among the longest natural soft fibres on the planet and are also high in cellulose (Mahapatra, 2018). Hemp is regarded as a long-term product that will profit from consumer demand for environmentally friendly goods. Paper, carpets, biodegradable auto parts, salad oil, construction material, cosmetics, and steroid-free and anti-biotic-free fog food are just a few of the items made from industrial hemp (Lin et al., 2005; Crini et al., 2020).

Hemp is a close cousin of the marijuana plant, and the two are visually identical (Mark et al., 2020). Hemp, on the other hand, lacks marijuana's psychoactive properties. The stigma associated with the growth of hemp has made cotton more viable and a primary choice in textile industries. With time again and again hemp as proven to be a better substitute of cotton both in terms of production and yield and as well as in terms of lower potential ecological footprint. It is high time, hemp as a whole or as blends should be introduced and also replace many other synthetic and natural fiber that have any sort of detrimental effect in environment for commercial textile production (Andre et al., 2016).

The textile and clothing industries are among the most polluting industries in the world (Franco, 2017). One of the three methods indicated to alleviate such environmental repercussions is the use of sustainable materials in the production of clothes (Resta et al., 2016). Cotton is currently one of the most widely produced natural fibres, requiring extensive usage of water and chemicals (such as insecticides and fertilisers) (Franco, 2017; Sandin and Peters, 2018). Due to rising clothing demand, environmental concerns, raw material resource requirements, and ecological repercussions, a sustainable and cost-effective alternative natural fibre is necessary (Kostic et al., 2008).

The production of one kilogram of cotton requires an average of 10000 liters, whereas growing hemp significantly requires less water which is approximately 2,700 liters of water per kilogram. Hemp, on the other hand, thrives in the absence of pesticides. In addition, compared to cotton, hemp farming requires less land. Hemp can yield crops three times the size of cotton on an acre. On the same area, hemp produces 250 percent more fibre than cotton and it has the largest output per acre of any natural fibre. Hemp has a shorter growth season, with an average of 90 to 100 days compared to 150 to 180 days for cotton (Maria Bellotto, 2021).

Hemp plants store carbon from the atmosphere and let nutrients into the soil, making it more beneficial, whereas cotton requires pesticides that are hazardous to the environment and people. Cotton contributes approximately 16% of global pesticide emissions. Cotton requires massive amount of chemicals, which when discharged into the atmosphere can be hazardous to individuals and the planet. Cotton is reported to consume approximately half of all pesticides sprayed globally (Kooistra et al., 2006). Hemp, on the other hand, thrives in the absence of pesticides. Pesticides applied on agriculture can harm wildlife as they grow, polluting other commodities that eventually wind up in food (Aktar et al., 2009).

Fabrics made from hemp fibres are more lasting, stronger, and preserve their shape when strained. In textile form, hemp easily mixes with other fibres but is also very adaptable; different portions of the plant are suitable to different purposes. Because of the numerous advantages linked with hemp, it is becoming increasingly popular for a variety of uses. The rising use of hemp in near future time appears to be unavoidable. Hemp fabric is considered more comfortable for people who have chemical intolerances since it is natural. Hemp bast fibres are thought to be among the best naturally soft fibres. In comparison to cotton, hemp helps to keep the wearer warmer in the winter and cooler in the summer. Hemp is more effective at blocking the sun's harmful UV rays. When Hemp is combined with other fibres such as Cotton, Linen, and Silk, it produces sturdier, longer-lasting products while retaining the quality and softness of Hemp (**Schwartz, 2010).**

Fabric formation is the process of fabric formation by the assembly of fibers, yarns or combination of these. There are many ways to manufacture a fabric. Weaving is the interlacement of warp and filling yarn to form a fabric. These yarns run parallel to each other and warp run along the lengthwise direction of the weaving machine (Adanur, 2001). There are many ways to interlace warp and weft yarn, each resulting in a different fabric structure and characteristics.

There are three basic weaves: plain weave, twill weave and satin weave. Most of the weave structures are derived from these 3 basic weaves. Some weaves are difficult to connect to the aforementioned weave structures. Twill weave is a multi-functional weave made up of two or more weft strands that alternate over and beneath one or more warp strands. The twill weave has a highly distinct design with a prominent diagonal line across the cloth, yet the backside has a smooth face with an opposing design (Adanur, 2020).

The growing interest in hemp textiles is due to an appreciation for the benefits that the hemp plant can provide, as well as a growing societal awareness in terms of creating demand for bio-based products and protecting ecosystems to ensure long-term solutions for a circular bio-economy (Košir et al., 2021).

Based on the above background and information the following objectives were proposed for the thesis entitled **“Development and Evaluation of Sustainable Woven Fabric Produced from Recycled Cotton and Hemp”:**

- To select the raw material: recycled cotton and hemp yarn.
- To prepare fabric using suitable fabrication method and to prepare sample.
- To evaluate subjective and objective quality parameters.
- To design and develop a suitable end product.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Literature reviews are important for assessing what has been published on a subject, evaluating the degree to which a specific research area reveals any trends, collecting facts relevant to a specific research study in order to promote evidence-based practise, developing new frameworks and theories, and identifying subjects that require further investigation (Pare et al., 2015). This chapter is discussed under the following sections:

2.1 Natural fibers

2.1.1 Classification of natural fibers

2.1.1.1 Vegetable fibers

2.1.1.2 Animal fiber

2.1.1.3 Mineral fiber

2.2 Hemp: The plant fiber

2.2.1 Introduction

2.2.2 History

2.2.2.1 Origin of hemp

2.2.2.2 History of hemp in India

2.2.3 Cultivation and extraction of hemp fiber

2.2.3.1 Cultivation

2.2.3.2 Hemp processing

2.2.3.2.1 Retting

2.2.3.2.1.1 Dew retting

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2.2.3.2.1.3 Chemical retting

2.2.3.2.2 Decortication

2.2.3.2.3 Hackling

2.2.3.2.4 Spinning

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2.2.4 Basic morphological feature of hemp

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2.8.3 Satin weave
2.8.4 Other fabric designs
2.9 Product development

2.1 Natural fibers

Fibers are thread-like materials that resemble hair. These are distinct elongated continuous strands. They can be spun into yarns, thread, or rope, and they can even be utilized as raw material for composites. It can be matted into sheets and can be used to create paper or felts. There are two types of fibers: natural and synthetic fibers (Chandramohan and Marimuthu, 2011). Synthetic fibres pollute both air and water during production and processing, and the litter generated after consumption is non-biodegradable and can result in the release of harmful greenhouse gases. Natural fibres have an edge over synthetic fibres in light of growing environmental concerns; therefore, many studies and investigations have been conducted in the last few years to find various natural fibres (Nandan et al., 2008).

Natural fibers are easily available and have high yield potentials in various industrial and commercial applications. They find its use in variety of technical textiles such as in interior applications for both buildings and automobiles as partition boards and false ceilings, in geo-textile for soil reinforcement and erosion control and many others. Due to its variety of reach, natural fibers are today more encouraged to be used in branches of technical textiles. With the increase and continuous research and development, utilization of natural fibers for the same has received significant growth (Dhaliwal, 2019).

2.1.1 Classification of natural fibers

Natural fibres are those produced by plants, animals, and minerals. They are divided into sub-categories based on their origin (Bhatnagar, 2007). Plant fibers include bast or stem fibers, leaf, seed, fruit, wood, cereal, straw and other grass fibers. Plant or vegetable fiber which are rich in cellulose, and fibers of flax, hemp, coir and sisal have lower amount of cellulose and higher amount of lignin (Anandjiwala, 2007), while animal fibers comprises of proteins (hair, silk and wool). Natural fibers in majority comprises of cellulose, hemicelluloses, lignin, pectins and waxes (John and Thomas, 2008). Classification of natural fibers is shown in Figure I

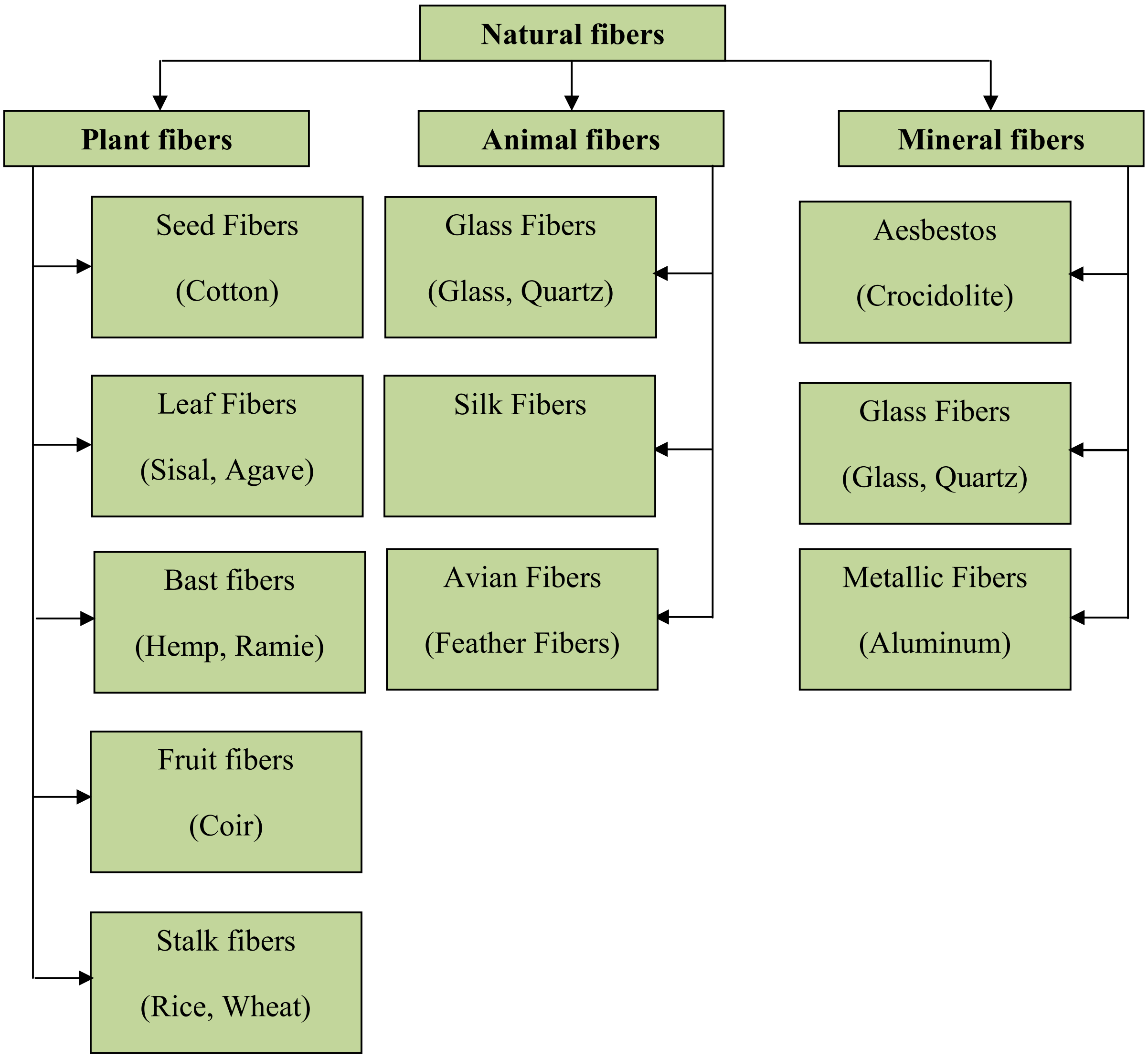


FIGURE - I

CLASSIFICATION OF NATURAL FIBERS

2.1.1.1 Vegetable fibers

Vegetable or plant fibers generally comprises of cellulose. Cotton, jute, hemp, sisal, ramie, and flax are some of the examples of vegetable fiber (Güven et al., 2016). These fibers are further categorized into the following:

- **Seed fiber**: Fibers collected from seeds or seed cases. E.g. cotton and kapok.
- **Leaf fiber**: Fibers collected from leaves. E.g. sisal and agave.
- **Bast fiber or skin fiber**: Fibers are collected from the skin or bast surrounding the stem of the respective plant. These fibers have higher tensile strength than other fibers. Some examples are flax, jute, kenaf, industrial hemp, ramie, rattan, soybean fiber, and even vine fibers and banana fibers.
- **Fruit fiber**: Fibers are collected from the fruit of the plant, e.g. coconut (coir) fiber.
- **Stalk fiber**: Fibers are actually the stalks of the plant. E.g. straws of wheat, rice, barley, and other crops including bamboo and grass. Tree wood is also such a fiber.

2.1.1.2 Animal fibers

Animal fibers generally comprise proteins; examples include silk, wool, angora, mohair and alpaca (Hassan, 2012).

- **Animal hair (wool or hairs):** Fiber or wool taken from animals or hairy mammals. E.g. sheep's wool, goat¬ hair (cashmere, mohair), alpaca hair, horse hair, etc.
- **Silk fiber:** Fiber collected from dried saliva of bugs or insects during the preparation of cocoons. Examples¬ include silk from silk worms.
- **Avian fiber:** Fibers from birds, e.g. feathers and feather fiber.

2.1.1.3 Mineral fibers

Mineral fibers are naturally occurring fiber or slightly modified fiber procured from minerals (Chandramohan and Marimuthu, 2011). These can be categorized into the following categories:

- **Asbestos:** The only naturally occurring mineral fiber. Varietions are serpentine (chrysotile) and amphiboles (amosite, crocidolite, tremolite, actinolite, and anthophyllite).
- **Ceramic fibers:** Glass fibers (Glass wool and Quartz), aluminum oxide, silicon carbide, and boron carbide.
- **Metal fibers**: Aluminum fibers

Fibers derived naturally from plants, animals and minerals are natural fibers while those synthesized through means of chemical processes are man -made fibers. A global economy is sustainable when the development does not interfere with the living standards and purchasing power of the future generation without exhausting the resources. To achieve sustainable economy, the need of the hour is to grow or develop sustainable resource. These resources can be re-grown or reused in upcoming days without posing any threat on global biodiversity for future generation (Ho Mei et al., 2011).

Global fiber production in 2017 exceeded 100 million mt accounting for the largest fiber production ever. From 10million mt to 100 million mt, it was a 10 fold increase from 1950 - 2017. Since 1990s synthetic fibers have been dominating the fiber market and since then it has overtook cotton as the dominating fiber. Synthetic fiber s made upto 65 million mt of total fiber production in 2017, making it worth for approx 60% of global fiber production, of which polyester alone is accounted for 51% share of market in global fiber production (Exchange, 2019).

Cotton is the second most important fiber after synthetic fibers. It constitutes for approximately 25% of global fiber production. Jute, hemp, linen and other plant based fiber accounts for roughly 5 % of the market share in global fiber production. Over the years there has been a significant increase in fiber production which results in increased consumption and large amount of textile waste. With the ongoing concerns and awareness there is an urgent need for use of resources that can grow without increase in resource consumption. These innovations will help to reduce the carbon footprint of fibers on environment (Juanga-Labayen et al., 2022).

2.2 Hemp: The plant fibers

2.2.1 Introduction

Cannabis sativa L is one of the world's oldest crops known to man. It has been cultivated since the Medieval Era for the commercial application of bast fibre present in the stem, the multi-purpose oil in the achenes, and an intoxicating resin generated by epidermal glands. Industrial hemp and Indian hemp are additional terms used to refer for the same plant. Hemp (Cannabis Sativa L) is an annual plant that can grows to a height of 1 to 5 metres, depending on the type of plant and growing conditions (Fike, 2016).

Industrial hemp is a deep-rooted herbaceous plant with a tap root. It is a perennial plant that requires a certain number of consecutive short days to flower. It is a tall, slender plant with no branches. Brancheless plants are mainly cultivated for commercial purposes. The stem diameter ranges from 10mm to 40mm. It has a narrow woody stem. It grows to a height of 4.0-5.0m in 160-210 days. It grows swiftly and is harvested from the stalk of the plant. It is a fast-growing plant that can reach a height of 0.31 metres in less than a week (Primefact 801, July 2008).

Hemp can grow rapidly which makes it ideal for production. Hemp is a bast fibre. The stem's innermost section is composed of a woody core. Bast fibres, in respect to other fibres, have a higher tensile strength. These fibres have a wide spectrum of applications and can be utilized in a variety of sectors. The fibre are available in creamy white, dark tan brown, grey, black, or green color (Singh, 2010). Tetrahydrocannabinol (THC), a psychoactive (mind-altering) component present in Cannabis sativa, is synthesized in specialised glands. Industrial hemp contains significantly less THC than marijuana and is the fundamental factor that distinguishes it from marijuana (Primefact 801, July 2008).

Hemp fibers have many desirable features over other fibers that set it apart. These are highly absorbent, stronger, protection against sunlight and no allergic effects (Kostic et al., 2008). They do not attract pests; therefore use of pesticides is not needed. Fabrics made of woven are comparatively stronger than cotton and can effectively block at least 50 per cent sun rays than other fiber (Duerr, 2011). Although hemp has many desirable features yet cultivating hemp requires special permission and license in many places while some places have imposed ban on growth of hemp.

2.2.2 History

History of hemp is discussed under following headings:

2.2.2.1 Origin of Hemp

- **8000 BCE:** The first clear signatures of hemp's entry into human lives were cords from China and Taiwan, as well as hemp cloth from ancient Mesopotamia.
- **2000 BCE – 800 BCE**: Hemp spreads eastward to the Korean Peninsula and Japan, and southward to the Indian subcontinent. Cannabis is designated as sacred grass by the compilers of Atharvaveda. By 1200 BCE, the plant had spread throughout ancient Egypt.
- **800 BCE – 200 BCE**: Hemp reaches across Asia, North Africa, and the eastern Mediterranean. Around 800 BCE, the Scythians from Central Asia bring cannabis to modern-day Germany, and by 200 BCE, the Greeks are promoting the plant's curative properties.
- **200 BCE – 500:** Hemp paper is made in China.
- **500-1000**: Hemp has spread to the outskirts of modern-day Europe. Hemp is introduced to the Iberian Peninsula as a result of the Moorish invasion. By the year 1000, hemp is the preferred material for ropes and cordages from southern Russia to Greece, Spain, and the British Isles.
- **1000 – 1450**: Hemp makes its way into Sub-Saharan Africa.
- **1492**: Hemp fibre is used to make sails and ropes for Christopher Columbus' ships.
- **1533:** England recognises hemp's commercial potential and directs English farmers to cultivate the lucrative crop.
- **1606 – 1616**: Hemp was used in a variety of ways by early American farmers, from ship rigging to lamp fuel.
- **1632 – 1700**: Hemp's strategic contribution to economy is recognized, and by the end of the century, farmers across the colonies are obliged to grow hemp as a staple crop.

- **1937**: Hemp and marijuana are entangled in crossfire. The Marijuana Tax Act is implemented by the American Congress, imposing high taxes on all cannabis varietals, including hemp.
- **1942 – 1945**: Due to Japan's invasion of the Philippine Islands, America has managed to lose its major source of imported hemp. The *Hemp for Victory* campaign begins the process of lifting the prohibition on hemp production and cultivation.
- **1970**: Hemp is classed as a Schedule 1 drug in the United States, making its cultivation and consumption illegal.
- **1998**: Because the government can no longer overlook the surging domestic demand for hemp products, restrictions on the import of food-grade hemp were lifted.
- **2004**: The Hemp Industries Association persuades the 9th U.S. Circuit Court to grant permanent protections for domestic imports and sales of hemp-based food and baby-care products.
- **2007:** The state introduced the first permit for American hemp cultivation in over five decades.
- **2014**: The government initiates the well-known Farm Bill, which encourages state agriculture departments and research institutes to oversee pilot research programmes for hemp cultivation.
- **2017**: In the three years since the Farm Bill was passed, more than 25,000 acres of American hemp have been planted by nearly 15,000 farmers across 19 states. At the same time, over 30 various research establishments are investigating hemp (itshemp, 2018).

2.2.2.2 History of Hemp in India

- Cannabis has been regarded one of the five divine plants in Hinduism since before the compilation of the Atharvaveda. Cannabis is lexicalised as charas (resin), ganja (flower), and bhang (seeds and leaves) in local linguistics.
- The cannabis Sativa plant was one of many plants used to make soma during the Vedic period. The plant and its numerous medicinal perks are acclaimed in the Rigveda, Atharvaveda, Ayurvedic texts, and tantric texts.

- **1798**: In an attempt to minimise cannabis consumption, the British Parliament imposed a cannabis tax.
- **1838, 1871, and 1877**: The government dismisses these advances.
- **1961**: Cannabis is classified as a hard drug under the Single Convention on Narcotic Drugs, an international treaty. India agreed to constrain Indian hemp exports.
- **1985**: The Indian government enacted the Narcotic Drugs and Psychotropic Substances Act in 1985, which prohibited the production and sale of cannabis resin and flowers but permitted the use of Cannabis leaves and seeds.
- **2015**: The Great Legalization Movement India is attempts to re-legalize cannabis for industrial and therapeutic reasons in the country. Cannabis is recognized as a source of biomass and fibre under the National Policy on NDPS. Cannabis cultivation for industrial and horticultural purposes is approved (legal) in India.
- **July, 2019:** The Delhi High Court accepted to acknowledge a plea filed by the Great Legalization Movement Trust challenging the ban on cannabis, describing its classification with other drugs under the NDPS Act as "arbitrary, unscientific, and unreasonable."
- **November 7th, 2019**: Following this hearing, the Delhi High Court issued a notice to the central government, questioning the prohibition and criminalization of its use for industrial and medicinal purposes. The decision is seen as altering the course of hemp history in India (itshemp, 2018).

2.2.3 Cultivation & extraction of hemp fiber

2.2.3.1 Cultivation

Hemp grows best in temperate climates. It takes 3-5 months to grow with an adequate amount of rainfall of 10-12 inches. Hemps are ideally harvested just several inches above the ground using equipments such as sickle mower or disc mower. The stalks are chopped and allowed to dry. Hemp stalks are made up of two types of fibre: bast fibre and hurd fibre. Bast fibres are long and found in bark, while hurd fibres are short and found in the stem. Hemp is a thermophilic and heliotropic crop, which means it requires a lot of warmth and sun to thrive, without it, seed production and biomass deteriorate. Hemp finds its origin in Central Asia. It has now spread to a number of countries, including Canada, the United States, France, Italy, Germany, the Philippines, and India, to mention just some (Grabowska et al., 2009).

Hemp is a seed-bearing perennial plant. It grows best on land where a variety of crops are grown in one area at different times of the year; this is known as crop rotation. This practice, combined with the use of few or no agrochemicals, increases the soil's nutrient requirement. The soil must be well-drained, nitrogen-rich, and acid-free. Because it attracts few pests, hemp grows quickly and requires few pesticides. It can be grown organically with ease. That is, it does not require the use of artificial pesticides, herbicides, or fertilizers, and thus can contribute significantly to a more sustainable future (Carus and Sarmento, 2016).

Natural and organic fibres are becoming increasingly popular as a result of current insights and awareness of the natural and healthy characteristics associated with the use of appropriate textiles. Hemp has a longstanding tradition history. Today, the significance of hemp is recognized, with it being capable of producing textiles, paper, rope, and oil since the days of our forefathers. Hemp is known as the "hundred-use fibre." Hemp was so important in the 16th century that King Henry VIII passed legislation fining farmers who failed to grow the crop. Hemp is used not only in textiles and fabrics, but also in paper production. China has the world's oldest piece of hemp paper, which is over 2000 years old. Bast fibre plants are distinguished by the outer portions of their stalks, which contain long, slender primary fibres. Pectin, a glue-like soluble gelatinous carbohydrate, connects the primary hemp fibre to the core fibre (Mahapatra, 2018).

2.2.3.2 Hemp Processing

Hemp processing in textiles undergo following process:

2.2.3.2.1 Retting

The process of dissolving the tough cellular tissue of hemp stalk is known as retting. It entails the use of microorganisms on the stem, in the soil, or through the use of special enzymes The microbes break down the pectin or chemical bonds that hold the stem together, making it easier to separate the bast from the plant's core. Controlled retting is a process that requires a skilled hemp farmer to oversee (Paridah et al., 2011). There are mainly three kinds of retting

2.2.3.2.1.1 Dew retting

Dew retting is the only type of retting that can be done on the field, whereas other types of retting necessitate the use of a special facility. The stalks of hemp are cut as close to the ground as possible. They are spread out on the ground and exposed to environmental conditions such as dew or rain (Franck, 2005).

2.2.3.2.1.2 Water retting

This method involves soaking dry hemp stalks in bacteria-infested water tanks, ponds, or rivers. Water softens the outer layer while encouraging the growth of more bacteria, accelerating the retting process. Although it is more expensive, the water retting process produces higher quality fibre. It is accomplished through natural water retting in slow moving water such as ponds, bogs, or streams, or through retting in concrete tanks. Double retting is the process of removing stalks from water before retting, drying for a few months, and retting again. This method is well-known for producing high-quality fibres (Paridah et al., 2011).

2.2.3.2.1.3 Chemical retting

The constituents of the bast fibre are broken down using acid and special enzymes in this process. They are boiled in treatments containing chemicals such as sodium hydroxide, sodium chloride, sodium sulphite, hydrochloric acid, and oxalic acid. It is an expensive procedure (Nugistics, 2021).

2.2.3.2.2 Decortication

Hemp decortication is the process of separating the soft exterior of the hemp plant from its tough, woody interior. Decorticator is a mechanical device used to separate hemp fibre by passing stalks through a fluted roller that breaks the hurd into small pieces. Scutching is a mechanical process that requires striking the stems with a beech stick or passing fibres through rotating blades to remove any leftover hurd pieces. Modern decorticating procedures include steam explosion and ultrasonic breaking (Zimniewska et al., 2017).

2.2.3.2.2 Hackling

Hackling is the removal of short and medium-sized fibres from stalks using a special cutting tool. It extracts stalks ranging in length from 3 m to 650 mm. It cleans the fibre and integrates it for spinning (Müssig et al., 2020).

2.2.3.2.2 Spinning

Before spinning, the fibres are passed through a trough of hot water to further treat them for a finer yarn. This is referred to as wet spinning. It softens the pectin and allows for further fibre separation (Salmon-Minotte, 2005).

2.2.3.2.2 Bailing

Hemp fibres are formed into bales for long-term storage. Large, round bales allow hemp to dry more quickly than square bales. They are kept in a dry, less humid environment to prevent growth of mold (Nugistics, 2021).

2.2.4 **Basic morphological features of Hemp**

Figure -II Basic morphological features

(Source: Primefact 801, July 2008, INDUSTRIAL HEMP– A NEW CROP FOR NSW)

The basic morphological features of Cannabis Sativa are 1. Flowering branch of male plant. 2. Flowering branch of female plant. 3. Seeding 4. Leaflet. 5. Cluster of male flowers. 6. Female Flowers, enclosed by perigonal bract 7. Mature fruit enclosed in regional brat. 8. Seed (achene), wide face. 9. Seed, narrow face. 10. Stalked secretary gland. 11. Top of sessile secretary gland. 12. Long section of Cystolith hair.

2.2.5 Properties of hemp

2.2.5.1 Physical Properties:

The physical properties of hemp fiber are as follows (Patwary, 2012):

- **Color**: Hemp fibre is yellowish grey to deep brown in colour.
- **Length**: Hemp fibre has a length of 4 to 6.5 percent feet.
- **Tensile strength**: Hemp is a very strong fibre in terms of tensile strength.
- **Elongation at break**: Hemp fibres are prone to stress.
- **Elastic recovery**: the elastic recovery rate is extremely low. It is less than linen fibres.
- **Moisture regain**: Hemp has a standard moisture regain of 12 percent. There's more to it than just cotton and linen.
- **Effect of heat**: Hemp fibre is extremely resistant to heat damage.
- **Effect of sunlight**: It has the ability to protect against the negative effects of sunlight.
- **Luster**: Like linen fibre, it has a high luster.

2.2.5.2 Chemical properties:

The chemical properties of hemp fiber are as follows (Patwary, 2012):

- **Effect of acids**: Hemp is attacked by hot dilute acid or cold concentrated acid, which causes it to dissolve.
- **Effect of alkalis**: Hemp fibre has an excellent resistance to action of alkali.
- **Effect of organic solvent**: It is immune to organic solvent.
- **Effect of insects**: Moths, grubs, and beetles have no influence on hemp.
- **Effect of microorganism**: It is attacked by fungi and bacteria. Mildew feeds on fibre, causing the material to deteriorate. Under hot and humid conditions, it can flourish on hemp. Chemical impregnation can be used to protect them. One such chemical is Cooper nepthenate.
- **Ability to dye**: It is not appropriate for dyeing. Hemp fibre is dark tan or brown in color and is difficult to bleach; however, it can be dyed bright and dark colors.

2.2.6 Advantages

The advantages of hemp are as follows:

- It is an effective agent for removing soil contaminants such as Zinc and Mercury. As it is bug and fungal resistant, Industrial Hemp does not require fertilisers or pesticides. It is an effective agent for removing soil contaminants such as Zinc and Mercury (Kadolp and Langford, 2002).
- Hemp is an environmentally friendly material that is renewable, reusable, and recyclable. Hemp grows effectively in regions where herbicides, fungicides, and pesticides are not used. As a consequence, it is chemical-free.
- The tensile strength of the fibre is higher than that of many other vegetable fibres. The fibre is strong and long-lasting.
- Hemp is more durable than cotton. As a result, it is used in industries to make stronger fabrics such as strings, cord, and rope.
- Italian hemps are produced with great care; they are light in color and have lustre similar to flax. Hemp fiber is more lignified than flax fiber and thus stiffer.
- Hemp strands have microscopic alcoves that make them air permeable and highly absorbent. Hemp fabric keeps the wearer cool in hot weather and warm in cold weather. The catacombic buildup allows the body to warm air trapped in the fibres.
- Products made with hemp fabrics retain shape due to low elasticity of fiber.
- According to a 2010 Stockholm Environment Institute study, the ecological footprint of hemp fibre is one-third to half that of US cotton.
- It is extremely resistant to harmful UV rays and will not fade in the sunlight.
- It dries quickly and resists bacteria and mildew growth, making it anti-microbial.
- It is machine washable; the fibres become softer and finer with each wash. It also sheds a microscopic layer that protects the surface from soiling and reveals a new one (Cook, 1993).

2.2.7 Uses of hemp

Hemp is referred to as a "super fibre," and it is used in the textile and fashion industries. There is plenty of room for hemp-based innovative sustainable product development. Many eco-friendly designers are looking into using hemp as a major clothing source (Schumacher et al., 2020).

Aside from its traditional use in textiles, hemp's recent relevance has led to its use in a variety of fields such as building and isolation materials, composite materials, special cellulose materials (papers), technical textile, geotextiles and agricultural textile, oil-based products, items for agriculture and horticulture, and so on (Farrington et al., 2005). Hemp is used in a wide range of commercial and industrial products, such as rope, textiles, clothes, footwear, food, paper, bioplastics, insulation, and bio-fuel (Keller, 2013).

Hemp was the world's most important agricultural crop, and it was also used to make paper and lamp oil. Hemp paper has been used since 200BC. Several well-known books, including the Bible, Mark Twain's novel, and other historical documents, were printed on hemp paper during this time period, and several famous artists painted on hemp canvas (Sheppard, 1998). It was popular until the 1930s, when it was replaced by paper made from trees. However, in recent years, many businesses have begun to return to using hemp paper

Trials can be conducted in cotton and synthetic spinning by incorporating Hemp fibre into a variety of value-added commodities and producing various forms of fancy yarn that can be sold at a premium in the market (Schumacher et al., 2020).

2.2.8 Market

The global industrial hemp market was valued at $4.9 billion in 2019 and is expected to grow at a CAGR of 22.4 percent from 2021 to 2027, reaching $18.6 billion by 2027. Industrial hemp, sometimes known as hemp, is a type of Cannabis sativa plant that is grown specifically for commercial purposes. The global industrial hemp market was valued at USD 4.13 billion in 2021 and is expected to grow at a compound annual growth rate (CAGR) of 16.8 percent from 2022 to 2030. The global demand for industrial hemp from application industries such as food and beverage, personal care, and animal care is driving the market.

The industrial hemp market has been categorised based on type, application, source and region. The industrial hemp market is divided into four types: hemp seed, hemp oil, hemp fibre, and others. Food and drinks, textiles, personal care items, pharmaceuticals, and other applications are researched in the global market. The market is divided into two categories based on the source: conventional and organic. Region wise, the market is studied across North America, Europe, Asia-Pacific and LAMEA (Chouhan et al., 2020).

Asia Pacific led the market, accounting for more than 32% of global revenue in 2021. China, India, Japan, Korea, Australia, New Zealand, and Thailand are all actively involved in the production and consumption of industrial hemp and its byproducts such as fibre, seed, hurds, and oil. Increasing global product demand, as well as advancements in technology and innovation, are making harvesting easier for cultivators, and thus changing the face of hemp production in the region (Hemp report market report, 2022).

2.3 Consumer waste

Any textile material that is not appropriate for further use is considered as textile waste. The end user could be a garment manufacturer, upholstery designer, carpet manufacturer or the final consumer. It could be any industrial waste generated while manufacturing of fibers, yarns, fabrics or garments or the household waste created after usage of garments or textile material by end consumers. Both industrial and household waste is recyclable and disposing of the same should be our last resort.

Textile waste can be classified as (i) pre-consumer textile wastes, (ii) post-industrial textile wastes and (iii) post-consumer textile wastes

Pre Consumer Textile Waste: these wastes are generated during textile, yarn, fabric or garment production and they do not reach consumers. These wastages are usually used as raw material in automotive industry, furniture, mattresses, home furnishings, paper and other related industries.

Post Consumers Textile Waste: The textile waste generated at various levels after usage of the finished product by end consumer and could be any clothing or household article which has been discarded or not in use for any reason like being worn out, damaged or outgrown are considered as post consumer textile waste. The majority of this waste comes at household level hence its management is an issue as industrial waste is easy to manage in comparison to household waste (Kapila et al., 2019).

Post-Consumer Textile Wastes: are wastes generated by consumers, and they are often clothing that are ready for disposal or landfill (Muthu, 2017).

2.3.1 Sustainability

Sustainability or the ability to sustain may be defined as development that meets the needs of the present without compromising the ability of future generation to meet their own needs. Sustainability is the concern in 21st century. Today it is a necessary approach towards an environment which should be preserved not only from harmful or toxic products but also a step to extract the maximum benefits from products by extending their life, before throwing them away.

The society today is fashion conscious. Clothing has become a "discard-style product," cheaply made out of poor material. Frequent changes in fashion mean that clothes can become outdated very quickly, and this encourages the replacement and disposal of outdated, yet good quality garments. The fast fashion today has paved way for manufactures to increasingly develop high quantities of low durability clothing in response to a ‘throwaway society’ (Kapila et al., 2019). "Fast fashion" as a trend has been widely criticized for eroding environmental resources and contributing to the destruction of our environment (Jung and Jin, 2016).

2.3.2 Recycled cotton

Recycled cotton is characterized as the conversion of cotton fabric into cotton fibre that can be reused in textile products. Cotton that has been recycled is also known as regenerated cotton, reclaimed cotton, or shoddy.

Fashion industry is responsible for large amount of waste, carbon emissions, pollution, water, and energy consumption. Cotton production usually requires a large amount of water, energy, labor, pesticides, and insecticides, whereas recycled cotton necessitates far fewer resources than conventional or organic cotton. Cotton recycling can help to reduce the environmental impact of discarded clothing. It can lessen the number of textile wastes that are chucked in garbage. It significantly reduces the environmental impact of cotton production. One tonne of cotton recycled can save up to 765 cubic metres (202,000 US gal) of water (Assoune, 2022).

2.4 Cotton

2.4.1 Introduction

Cotton's performance as a vital raw resource for the textile industry is unmatched among natural and synthetic fibres. Cotton fibres have been utilised in almost all types of textiles because they have a unique combination of physical and chemical properties that make them easy to prepare and appealing to use (Kadolph, 2010) (Collier et al., 2009).Cotton's natural properties provide textile and apparel consumers with unrivalled comfort. According to research conducted on a variety of consumer groups around the world, the comfort consumers associate with cotton is both physical and psychological.

Cotton has dominated the worldwide textile fibre industry for the better part of two centuries as it possesses a unique set of intrinsic properties that make it an ideal raw material for manufacturers. Cotton enjoys a privileged relationship with customers who tend to trust it as a natural and safe choice in sensitive applications such as babywear and next-to-skin clothing. As a result, despite a general downturn in its competitiveness when compared to worldwide demand for textile fibres, cotton remains strong in certain applications. Synthetic fibre growth continues to outstrip cotton growth in other traditional textile applications, most notably in the nonwoven industry's non-conventional sector (Krifa and Stevens, 2016).

2.4.2 History of cotton

- **5000BC**: Cotton fibre and fabric pieces discovered in Mexico during this time period.
- **3000 BC**: Cotton was originally farmed for use as a fabric in the Indus River Valley.
- **2500 BC**: The Chinese, Egyptian, and South American civilizations start weaving cotton cloths.

- **300 BC**: Following the conquest of the Persian Empire, Alexander the Great brought cotton items into Europe. Cotton cloth, on the other hand, has remained pricey and has a restricted application.
- **100 AD**: Arab traders introduce muslin and calico cotton textiles to Italy and Spain.
- **1492**: In the Bahamas, Christopher Columbus discovers the contemporary world's most common cotton variety, Gossypium Hirsutum.
- **1530**: Naturally coloured cotton textiles are among the earliest products recovered from Americans, and they are more technically complex than cloth produced on European looms at the time.
- **1600**: The East India Company sends unique cotton textiles from India to Europe.
- **1700**: The international cotton industry expands rapidly as Britain buys cotton-growing colonies and textile manufacturing advances enable for stronger yarn to be spun.
- **1760**: As a result of the industrial revolution, Britain surpasses India as the world's largest cotton processor.
- **1920**: The United States accounts for more than half of the world's cotton fibre production.
- **1940**: Denim's popularity grows, and the perception transforms from rugged workwear to daily wear for the general population.
- **1945**: During WWII, naturally green and brown cottons are grown commercially to compensate for a scarcity of dyes.
- **1950-51**: Global cotton demand and production both hit seven million tonnes.
- **1980**: Colored cotton types are phased out in favour of pure white commercial variants.
- **2011**: World cotton prices reach their all-time highs.
- **2014-15**: China, the world's top cotton importer and producer, generates an estimated 33 million bales.
- **2015**: China's global cotton market share drops, and global cotton consumption growth slows (CottonAustralia, 2022).

2.3 Cultivation of cotton

Cotton is a tropical and subtropical crop that requires consistent high temperatures ranging from 21°C to 30°C. When the temperature drops below 20°C, cotton growth is slowed.

An average yearly rainfall of 50-100 cm may provide the modest water needs. It can, however, be cultivated well with irrigation in locations with less rainfall. Irrigated cotton covers almost a third of the entire area under cultivation. High rainfall early in the season and bright, dry weather during the ripening period are both beneficial to a healthy harvest. Cotton is a kharif crop that matures in 6 to 8 months. Its planting and harvesting times vary based on climate conditions in different parts of the country (Mondal).

2.4.4 Properties

2.4.4.1 Physical Properties:

The following are the physical properties of cotton fibre:

- **Color:** Cotton fibre can be white, creamy white, blue white, yellowish white, or grey in color.
- **Tensile strength:** Cotton's wet strength is 20% greater than its dry strength, indicating that moisture has a significant impact on its strength.
- **Elongation at break**: Cotton does not stress easily, thus elongation at the break is not a problem. It has a 5-1 percent elongation break.
- **Elastic Recovery:** Cotton is a stiff and inelastic fibre. It possesses a 74 percent elastic recovery at 2 percent extension and a 45 percent elastic recovery at 5 percent extension.
- **Specific Gravity**: Specific gravity of 1.54.
- **Moisture Regain**: Standard moisture regain is 8.5%.
- **Effect of heat**: Cotton has a high resistance to heat degradation. As a result of oxidation, cotton is severally damaged after few minutes at 240°C.
- **Effects of Age**: Cotton shows a small loss of strength when stored carefully. After 50 years of storage cotton may differ only slightly from the new fibres.
- **Effect of sunlight**: When cotton is exposed to sunlight, it gradually loses strength and the fibres turn yellow. When heat is generated and encouraged, cotton is degraded by oxidation. UV-light and the shorter strands of visible light produce much of the damage caused by sunlight (Islam, 2022).

2.4.4.2 Chemical Properties:

The following are the chemical properties of cotton fibre:

- **Effect of alkali**: It has a good preventative power. Cotton fibre is not harmed by alkali.
- **Effect of acid**: Strong acids eat away at the fibres. The fibre is harmed by concentrated sulphuric acid and hydrochloric acid. Weak acid does not harm the fibre.
- **Effect of bleaching**: Bleaching has had no negative consequences in this case. Strong oxidising bleaching converts cotton to oxi-cellulose.
- **Effect of organic solvent**: Resistance to dryness is conceivable here.
- **Effect of sunlight**: Sunlight has the effect of converting cotton into oxi-cellulose.
- **Effect of mildew**: Mildew has a difficult effect if left untreated. There is a chance that wearer will be impacted.
- **Ability to dye**: Affinity to color is good. Direct, reactive, sulphur and vat dyes are used.
- **Effect of insect**: Not affected by moth.
- **Effect of heat**: The conductive ironing temperature is 150°C, the decomposition temperature is 2400°C, and the igniting temperature is 390°C (Textile-tutorials, 2017)

2.4.5 Advantages:

- Cotton is naturally sustainable, biodegradable and versatile fiber.
- Cotton is a soft material that is easy to work with. It can easily stretch, making it a comfortable fabric to wear. Due to its softness and comfort, it is often used in underwear and undershirts.
- Cotton fabric is breathable and transmits moisture away from the body and is absorbent and removes liquid from the skin, like a towel. Cotton allows wearer to remain comfortable, keeping moisture from building up between skin and clothing.
- Cotton clothing protects against from heat in the summer and cold in the winter by providing thermal insulation as the cotton fabric traps air between the fabric fibers.
- Cotton has a high affinity for dye. Color retention capacity is good.
- Cotton has a high tensile strength, making it strong, durable and less likely to rip or tear. It is 30 percent stronger when wet, withstanding many washings in hot water.

- Cotton fabric rarely causes allergic reactions and wearing cotton is often recommended for those with skin allergies. Because cotton is hypoallergenic and does not irritate skin, it is used in medical products like bandages and gauze, and is the fabric of choice when it comes to baby clothing (Hasin, 2021).

2.4.6 Problem with cotton fiber

Cotton is the second most important fiber in terms of volume. With about 26 million tonnes, it had a market share of approximately 24 percent of global fiber production in 2020 (Textile Exchange, 2021). Organic cotton is a renewable, biodegradable, and sustainable material that is suitable for eco-fashion items. Organic cotton is grown without the use of hazardous chemicals such as pesticides or synthetic fertilizers. As a consequence, it doesn't pollute the water, land, or air, and it's really good for the environment. However, not all cotton is organic. In truth, the majority of cotton produced is not organic.

The use of pesticides and insecticides in non-organic cotton adds to environmental damage. Cotton growers and consumers are also exposed to harmful carcinogenic chemicals. It employs dangerous substances linked to cancer, hormone malfunction, and birth problems in both animals and people. Cotton demands a lot of water and energy to produce and harvest, whether it's organic or not. Irresponsible farming has rendered more than a third of the world's land useless - what was once lush agriculture has become a dismal wasteland. Although organic cotton reduces the environmental and social harm that pesticides may do, it does not address the massive energy and water consumption as well as the time it takes to replace the harvest (Ross, 2014).

2.4.7 Market

Cotton has also dominated the worldwide textile fibre industry for almost 200 years, due to advancements in cotton farming in response to increased fibre demand since the early days of the industrial revolution (Rivoli, 2009). Clothing consumes about two-thirds of all lint generated globally, followed by home furnishings and industrial textiles. Synthetic fibre manufacturers have practically infinite production capacity and the ability to influence fibre properties, while cotton has confined farmland and no efficient method of manipulating the naturally occurring and highly variable qualities of the fibres (Krifa, 2012; Krifa, 2013).

Cotton is a staple fibre, which means it is made up of fibres of different lengths. Cotton is manufactured from the natural fibres of cotton plants belonging to the Gossypium genus. Cotton is a soft and fluffy substance made mostly of cellulose, an insoluble organic component essential to plant structure. Cotton plants require a lot of sunlight, a considerable period without frost, and sufficient rain. Cotton refers to the portion of the cotton plant that grows in the boll and serves as the encasing for the fluffy cotton fibres. Cotton is spun into yarn, which is then woven into a soft, long-lasting fabric. Cotton fibres are composed mostly of cellulose, which accounts for roughly 90% of the total weight. In addition to this, water accounts for 5-8% of the weight, with the remainder being made up of various natural impurities (Gupta et al., 2005).

Cotton is regarded as a major worldwide commodity and is vital to numerous areas of the national economy (Narayanan, 2006). Cotton is grown in many different species in the Americas, Africa, Asia, and even Australia. China is now the world's leading producer of cotton, albeit the majority of it is used within the country. Cotton exports from the United States are the highest in the world. Uzbekistan, India, Turkey, Pakistan, and Brazil are also among the world's biggest cotton producers. Cotton is now a $425 billion-dollar-a-year multinational enterprise. Cotton textiles are utilised in a wide range of products, from undergarments to evening gowns to surgical dressings. Organic cotton cultivated without pesticides and processed in an ecologically responsible manner also has a strong market (Fuller, 2015).

Cotton develops inside the seed pods of several different plant species in the Gossypium family. Early primitive cottons grew naturally as perennials, and farmed cotton was likewise grown as a perennial for many years. Perennial cotton plants may reach heights of 6m (20ft) in the tropics. With just one or two notable exceptions, the majority of the world's cotton is now farmed as annual crops, with plants reaching a height of 1.2 to 1.8m (4 - 6 ft). Cotton seed is typically planted in the spring, and the immature plants are later trimmed out into rows.

Eventually, several creamy-white blossoms develop, which become pink by the end of the first day (Cook, 1993).

2.5 Recycled cotton

Recycled cotton is described as the process of converting cotton fabric into cotton fibres that may be reused in any manner. Recycled cotton is also termed as reclaimed cotton or regenerated cotton. Recycled or upcycled cotton is a clothing fabric even more environmentally friendly than organic cotton and performs just as well. Recycling also reduces CO_2 emissions when compared to the production of virgin materials. It limits textile waste caused by regular cotton production. Recycled cotton can be used in place of natural cotton. Its properties are similar to those of conventional cotton. The fabric is light, breathable, and dries quickly (Assoune, 2021).

2.5.1 Processing of recycled cotton

It is produced through recycling process which is mostly mechanical. Discarded fabrics are collected and sorted by material and colour. Following this separation, the textiles are torn into yarn and subsequently into crude fibre by a machine. The fibre is put under a lot of strain during this portion of the process, and it's quite simple for the fibres to break and become entangled. The acquired raw fibre is spun back into bobbins and utilised to make further clothing and accessories. The quality of the recycled fibre acquired via this procedure will never match the original fiber's quality (Piribauer and Bartl, 2019).

2.5.2 Advantages of recycled cotton

- **Less waste**

Reduce the amount of textile waste that is disposed of in landfills. A garbage truck carrying garments is predicted to arrive at a dump once per second. This equates to around 15 million tonnes of textile waste each year. Furthermore, 95% of textiles that end up in landfills might be recycled.

- **Save water**

Reduce the amount of water utilised in the textile manufacturing process by a significant amount. Cotton is a water-intensive plant, and real-world evidence of its impact is the loss of the Aral Sea in Central Asia, exists.

- **Environmentally friendly**

There is no need to use as many fertilisers, herbicides, or insecticides when we utilise recycled cotton. Cotton farming is estimated to be responsible for 11% of global pesticide usage.

- **Less CO_2 emissions**

Dyeing-related CO_2 emissions and water pollution are reduced. Textile dyeing is the world's second-largest water polluter, with the waste from the process sometimes deposited in ditches or rivers. There is no need to dye as the finished fabric is os the same color as of the waste cotton (Nuwastore, 2020).

2.5.3 Challenges of recycled cotton

Despite numerous challenges, recycled cotton is an excellent option for reducing textile waste and repurposing it for lower-quality products. A recycled garment cannot be recycled indefinitely due to the fibre separation process, which can weaken the fibre; recycled materials cannot be recycled indefinitely (Cottonworks, 2022). Even though recycled cotton has a well-established market, it is still expensive due to high production costs and limited availability because it is made from post-consumer or post-industrial cotton waste.

2.5.4 Uses of recycled cotton

The ultimate composition of the recycled cotton fabric will be determined by its intended usage. And, as a result, it must be combined with another fibre (for example, polyester) to enhance it, as the procedure alters the fiber's qualities such as length, uniformity, and resistance. It can't be recycled indefinitely.

Recycled cotton is a great way to cut down on manufacturing textile waste by recycling it in lower-quality items or by combining it with other fibres and repurposing it in fashion. There are significant obstacles to overcome for end usage, particularly in the clothing industry (Iribarren, 2018).

2.6 Fabric construction process

The process of fabric formation is defined as the assembly of fibers, yarns or combination of these. There are many ways to manufacture a fabric. Each manufacturing method can create a wide range of fabric structures, depending on the raw materials utilized, the equipment and machinery used, and the set up of control components within the processes. Man - made fibers are made from polymers, while plant and vegetable fibers constitute natural fibers. The fabric formed is then subjected to dyeing, printing and finishing based on the aesthetic or functional requirement of end product (Uddin, 2019).

There are many techniques through which fabric is formed: weaving, braiding, knitting, non woven and many others. Each of these major fabric manufacturing processes produces unique structures.

2.6.1 Weaving

Weaving is the process of interlacement of vertical and horizontal yarns called as warp and weft respectively perpendicular to each other. There are many ways to interlace warp and weft yarn, each resulting in a different fabric structure and characteristics.

2.6.2 Braiding

Braiding is the simplest method of fabric formation. Braided fabric is formed by interlacing of yarns that are diagonal to each other. Each set of yarns move in opposite direction. Unlike weaving, braiding does not require shredding, beta up and insertion (Kyosev, 2014).

2.6.3 Knitting

Knitting is the process of fabric construction that employs a continuous set of yarns to form series of interlocking loops called wales and course. Knitting in general is classifies as: warp knitting and weft knitting. In weft knitting, the yams flow along the horizontal direction in the structure (filling or course direction); in warp knit ting, they flow along the vertical direction (Purchas and Sutherland, 2002).

2.6.4 Non woven

A nonwoven is an engineered fibrous assembly, primarily planar, which has been given designed level of structural integrity by physical and/ or chemical means, excluding weaving, knitting, or paper making (EDANA).

2.7 Weaving

Weaving is the interlacement of warp and filling yarn to form a fabric. These yarns run parallel to each other and warp run along the lengthwise direction of the weaving machine (Adanur, 2001). Woven fabrics constitute of two sets of yarn namely warp and weft that mutually interlace to form a textile surface.

2.7.1 Mechanism of weaving

In weaving process, the warp yarns are arranged primarily of which some are then raised by harness, to create an opening called as shed. The weft yarn is inserted through the opening by means of shuttle, while the other warp yarns are held in place and once the shuttle passes the beater pushes the weft in place (House and Brean, 2000). The most common weaves include plain, twill, and satin, of which plain weave is most common and it is utilized most of the time (Petraco and Kubic, 2004).

2.7.2 Application of woven fabric

A fabric may be defined as a planar assembly of fibre, yarns or combination of these. There are various methods that can be applied to produce fabric. The most commonly used methods for fabric formation are weaving, knitting, and braiding. Non woven is also another process of fabric formation which involves of joining fibers either through adhesives or through bonding agents (Islam et al., 2021). Textiles are diverse in its application and are usually divided into fashion and clothing, household fabrics and technical textiles. Any textile product that is designed and engineered to confirm the functional aspects is technical textiles. Technical textiles are again categorized into classes based on its functionality (Wulfhorst et al., 2006).

Technical textiles are also known by terms such as industrial textiles, functional textiles, performance textiles, engineering textiles, invisible textiles and hi-tech textiles. Over the years technical textiles has seen indefinite increase in comparison to clothing and household fabrics. These textiles are manufactured primarily for functional and performance aspect it can offer rather than for its aesthetic or decorative feature it has to offer (Gale and Kaur, 2004). Today technical textiles have its own market and people are becoming aware and have increase urge to know everything technical textiles can offer. They are being used in various industries such as agro textile, clothing textile, construction textile, geo textile, eco textile, home textile, industrial textile, medical textile, packaging textile, protective textile, sport textile and transport textile (Rakshit et al., 2007).

2.7.3 Importance of blended fabric

Natural and synthetic fibers can be used as individual raw material or both can be used as blends to manufacture woven fabrics (Rajwin and Prakash, 2021). There are merits and demerits associated with a particular fiber, these demerits and shortcomings can be overcome by introducing another fiber that can neutralize and blend with other textile fiber or yarn (Ghosh, 2004). Blended fabrics unite different properties of all fibers involved in composition of fabric making, covering up the less desirable characteristic. They have an improved aesthetic and functional performance available in low costs and give different colors, texture (McArthur et al., 2001). Thus, the property of more than one type of fiber is implemented in a single fabric as a result of blending of fibers (Spencer, 2001).

2.8 Weave structures

There are three basic weaves: plain weave, twill weave and satin weave. Most of the weave structures are derived from these 3 basic weaves.

2.8.1 Plain weave

Woven fabrics come in various weave stricture of which plain, twill and satin are basic. Plain weave is constructed with two sets of yarns that run at one up and one down at right angles to each other. This type of weave produces fabric with good strength ad hard wearing, generally used as furnishing fabrics and as styling material (Sikdar et al., 2021). In this weave, the two sets of yarn stay perpendicular to each other and create a durable fabric. Each weft yarn passes the warp yarn by moving alternatively one above and one below and then so on. The subsequent weft yarn goes below the warp yarn that its belonging passes over and vice versa (Muzaffar et al., 2021).

2.8.2 Twill Weave and its derivatives

In this weave, each warp yarn starts to interlace on a different filling yarn and follows the same progression. Thus, the produced woven fabric has a diagonal line appearance. The twill weave produced seems to be a step wise progression of warp yarn interlacing pattern. This line is the characteristic design of the twill weave

The twill weaves are classified as left hand twill and right hand twill based on the direction of twill line. In right-hand twill, the twill line runs from lower-left to upper-right. In left-hand twill, the twill line runs from lower-right to upper-left. A fabric with a right-hand twill on the surface has a left-hand twill on the back. There are an unlimited number of twill weave variations. (Yazdi, 2015).

2.8.3 Satin weave and its derivatives

Satin weave is one of the fundamental types of textile weave along with plain and twill weave. Fabric with satin weave is characterized with glossy, smooth and glistening appearance. The right side of the fabric is shimmery while the wrong side has a dull form. In satin weave, four or more weft yarns float over a single warp yarn and four warp yarns float over a filling yarn. (Yazdi, 2015). A fabric is termed as "Satin", when the satin weave is made using filament fibers such as silk, polyester or nylon, while use of short fibers like cotton to form satin weave, the corresponding fabric is called "Sateen" (Stankard, 2015).

2.8.4 Other fabric designs

There are endless ways to weave a fabric producing different woven fabric designs. There are several sources that may necessitate the development of a new fabric style. The development of any design depends on the end use of product, fabric type and raw materials among other.

2.9 Product development

A new product concept is a declaration about expected product characteristics that would provide specific benefits over existing products or challenges (Crawford & Benedetto, 2003). A new product is one that has been on the market for five years or fewer and contains extensions and significant upgrades. In every competitive sector, new product creation is one of the riskiest, yet most important, tactics (Cooper, 2001). It is customary practise for every industry to consistently produce new goods in order to increase market share and, in certain cases, to ensure existence. Textile and garment industries are no exception; thus, they must produce new goods that incorporate innovation.

New product development techniques help to improve the marketing of new items. Several firms and products with varied textile end applications are developing innovative textile and garment goods. Various new product development procedures and tactics have been found via research and trade publications. Product developments include product that redefine existing products or redefeine entirely new ones. New category entries are products that are not new to the market yet drive an organization into a new category. The new category is a knockoff of an established product that allows an organization to enter new markets. Product line expansion products are new to the firm, yet they fit inside an established product line that the firm currently manufactures. These are the new goods that augment the firm's existing product lines (Kumar and Phrommathed, 2005).

Product Enhancements are products that are "not-so-new" items but are substitutes for current products in a company's product range. These exceed the previous product in terms of performance. Repositioning products are aimed at a new usage or application. Repositioning is the process of picking a new market place, addressing a new problem, and servicing another market demand for an existing product. Cost savings products that are aimed to replace existing products at a cheaper cost. New goods that generate cost savings can replace old items in the line while providing comparable advantages and performance at a reduced cost (Cooper, 2001).

METHODOLOGY

3. METHODOLOGY

This chapter deals with the description of the research procedure, techniques and instruments used to carry out the study under the following headings:

3.1 Selection of Raw Materials

- 3.1.1 Recycled Cotton Yarn
- 3.1.2 Hemp Yarn

3.2 Fabric Processing

- 3.2.1 Selection of Loom (Pit Loom)

3.3 Pre Preparatory Process

- 3.3.1 Warping
- 3.3.2 Sizing
- 3.3.3 Reeling

3.4 Weaving

- 3.4.1 Mechanism
  - 3.4.1.1 Primary
    - 3.4.1.1.1 Shedding
    - 3.4.1.1.2 Picking
    - 3.4.1.1.3 Beat Up Mechanism
  - 3.4.1.2 Secondary
    - 3.4.1.2.1 Take Up Motion
    - 3.4.1.2.2 Let Off Motion
  - 3.4.1.3 Auxiliary
    - 3.4.1.3.1 Warp Protector
    - 3.4.1.3.2 Weft Stop Motion
    - 3.4.1.3.3 Temples
    - 3.4.1.3.4 Brake
    - 3.4.1.3.5 Warp Stop Motion
- 3.4.2 Selection Of Weave

3.5 Evaluation

3.5.1 Subjective Evaluation

3.5.1.1 Visual Inspection

3.5.1.2 Suggestions for Product Preferences of Woven Samples for End Uses

3.5.2 Objective Evaluation

3.5.2.1 Physical

3.5.2.1.1 Fabric Weight

3.5.2.1.2 Fabric Thickness

3.5.2.1.3 Fabric Stiffness

3.5.2.1.4 Drapability test

3.5.2.1.5 Dimensional Stability

3.5.2.1.6 Fabric Count

3.5.2.2 Mechanical

3.5.2.2.1 Crease Recovery

3.5.2.2.2 Tensile Strength,

3.5.2.3 Comfort : Air Permeability

3.5.2.4 Absorbency

3.5.2.4.1 Drop Test

3.5.2.4.2 Wicking Test

3.5.2.4.3 Sinking Test

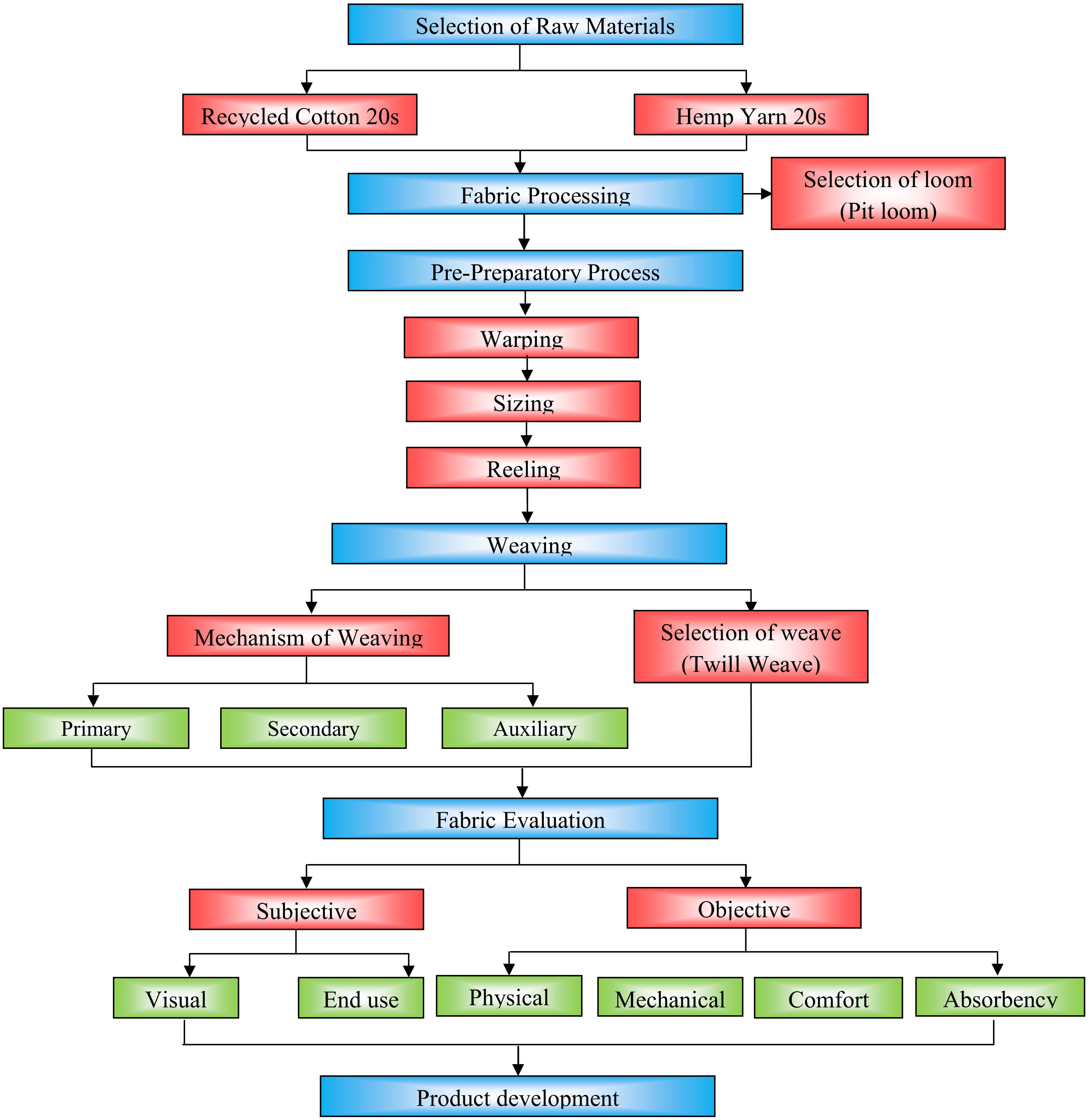
3.5.2.4.4 Spray Rating Test

3.6 Product Development

3.6.1 Construction

3.7 Statistical Analysis

FLOWCHART


Selection of Raw Materials
Recycled Cotton 20s
Hemp Yarn 20s
Fabric Processing
Selection of loom (Pit loom)
Pre-Preparatory Process
Warping
Sizing
Reeling
Weaving
Mechanism of Weaving
Selection of weave (Twill Weave)
Primary
Secondary
Auxiliary
Fabric Evaluation
Subjective
Objective
Visual
End use
Physical
Mechanical
Comfort
Absorbency
Product development

3.1 Selection of Raw Materials

Textile fibres are the raw materials used in the textile industry, which are spun into yarns and woven into fabrics (Shenai, 2001). Yarn manufacture is the process of transforming fibre into yarn. It is centered on natural fibres derived from natural plant or animal sources or chemically synthesized fibers (Uddin, 2019).

The yarns selected for study are: recycled cotton and hemp yarn.

3.1.1 Recycled cotton Yarn

Cotton fiber although produced naturally is not much sustainable when grown with the use of pesticides, chemical fertilizers, and insecticides and many other chemicals that are used in the production of crops for commercial purposes. It not only involves use of chemicals which are toxic and harmful both to environment and also to human health but also uses large amount of water and energy during its growth. Organic cotton is an alternative to avoid use of chemicals but the use of large amount of water is not avoidable (Coralie and Ineke, 2020).

Therefore, recycled cotton comes as a solution although not an indefinite solution but a solution nonetheless. The processing of recycled cotton involves shredding of waste fabric into its initial stage of fiber. The collected fabric waste is sorted according to color and material and then further processed to fiber and yarn for further processing (Coralie and Ineke, 2020).

Recycled cotton yarns of count 20 for thesis were sourced from Pallipalayam, Agraharam, Erode.

3.1.2 Hemp Yarn

Hemp is an amazing fiber which is converted into yarn. In comparison to other crops, hemp is peculiar in that every element of the plant has function and potential market value.

Hemp yarns of count 20 for thesis were also sourced from Pallipalayam, Agraharam, Erode.

3.2 Fabric processing

Fabric formation is defined as the joining of fibres, yarns, or a mixture of these. A fabric can be made in a variety of ways. The collected yarn is converted to fabric by the process of weaving. Weaving is the initial step in the production of cloth (Hayavadana, 2016).

3.2.1 Selection of loom

A shuttle loom is one in which the weft yarn is put through the warp strands using a shuttle. Pit loom is a form of loom in which the craftsmen produce the cloth by using pedals, and the foundation of pit loom is often stronger than handloom and may be used without latex. The warps are kept in tension between two beams, and in between healds are utilized with the assistance of two levers, which are linked with two paddles located inside the pit and used for shedding. Wefts are manually inserted within the shed. The warp threads are separated into two layers or portions, one above the other, to let the shuttle to pass through with a pick of weft (Harapanahalli, 2017).

The woven fabric produced is of length 3 meter and width of 15 inches. The pit loom is used due to the fact that the fabric produced is not in mass quantity and uses yarns like recycled yarn and hemp as warp and weft of lower count respectively.

3.3 Pre – Preparatory Process

There are a set of preparations to be made before the actual weaving process. The processes are:

3.2.1 Warping

Warping is the process of converting cones into a beam of specified dimensions. Warping is described in as the parallel wrapping of warp yarn or warp ends from cone, cheese winding bundles onto a warp beam. Warping should be done using the appropriate yarn bundles for the intended fabric quality or else fabric quality can be hampered (Gandhi, 2020).

3.2.2 Sizing

Sizing is an intermediate protective operation that is used to prepare yarn for weaving. Sizing is the process of putting a protective adhesive covering on the surface of the yarn. Sizing binds the yarn by attaching the strands together and thereby increasing yarn strength. It also improves warp yarn abrasion resistance. Lubricating the yarn surface in order to reduce friction during the weaving process aids in preventing inter strand tangling and surface abrasion. This friction reduction helps to keep the yarn intact, resulting in superior fabric quality (Goswami et al., 2004).

3.3.3 Reeling

The threads are independently attached on the reeling machine during the reeling process, and the warp yarn is rolled on a shuttle. The weft yarn is initially mounted on a charka before being rolled on the bobbin.

3.4 Weaving

Weaving is the technique of creating a cloth by interlacing warp and weft threads. Weaving machines, often known as looms, are machines that are used to weave. Weaving is an ancient craft that has been passed down through the generations. Today, a broad variety of looms are employed, ranging from the most basic handloom to the most complex machine. The omnipresent "simple power loom" is the most extensively used loom, especially when it comes to India (Islam et al., 2020).

Recycled cotton is selected as warp yarn with half of the yarn feed is red and the other half is white. Hemp is an amazing fiber which is converted into yarn and used as weft yarn. Weaving is done in Pallipalayam, Agraharam, Erode.

PLATE I

PREPARTION OF WARP

PLATE II

HEMP SHUTTLE

PLATE III

WEAVING LOOM

PLATE IV

WEAVING PROCESS

3.4.1 Basic mechanisms

On any sort of loom, the following mechanisms should be present, to generate a fabric by interlacing warp and weft strands:

3.4.1.1 Primary mechanisms

These mechanisms as the name suggests are essential for the production of fabric. And therefore, these mechanisms are called primary mechanism. There are three primary mechanisms at work. The three mechanisms are shedding, picking and then beat-up are performed sequentially (Fox, T. W., 2018).

3.4.1.1.1 Shedding mechanism

In shedding mechanism, the warp yarns from tunnel are divided into two layers which are called as shed.

3.4.1.1.2 Picking mechanism

The picking mechanism uses a shuttle to move weft thread from one selvedge of the fabric to the other through the shed. Pick is the term for a weft thread that has been inserted.

3.4.1.1.3 Beat-up mechanism

The mechanism involves pushing the newly inserted thread into the already woven fabric which is at this point called as fell of the cloth.

3.4.1.2 Secondary mechanism

These processes are secondary to the fundamental mechanisms in significance. These mechanisms are required if weaving is to be continuous (Fox, T. W., 2018). They are:

3.4.1.2.1 Take up motion

The take-up action takes the fabric from the weaving zone at a constant rate to provide the proper pick spacing before winding it onto a cloth roller.

3.4.1.2.2 Let off motion

The let off mechanism unwinds warp from the weavers beam and at constant tension at required rate delivers the warp to weaving area. The secondary motions are carried at simultaneous time.

3.4.1.3 Auxiliary mechanism

Auxiliary mechanisms are operations that although not necessary are essential to get high productivity and good quality of fabric. These are additional mechanisms added to plain power loom (Nagarajan, 2014). They are:

3.4.1.1.1 Warp protector mechanism

This mechanism involves halting of loom if the shuttle gets trapped between top and bottom layers of shed. Thus, it helps to avoid excessive damage to warp threads, reed wires and shuttle.

3.4.1.1.2Weft stop motion

The aim of this mechanism is to avoid cracks in fabric when a weft thread breaks or get exhausted.

3.4.1.3.3 Temples

Temple grips and holds the cloth at the same width warp in the reed, before it is taken up.

3.4.1.3.4 Brake

Brake ceases the movement of loom immediately when a warp thread breaks during weaving process.

3.4.2 Selection of Weave

There are three basic weaves namely, plain, twill and satin weave. Fabric of 2 x 2 twill weave is produced. Twill weave is a multi-functional weave made up of two or more weft strands that alternate over and beneath one or more warp strands.

A 2 x 2 twill weave is the most basic variant, with two weft strands alternating over one warp strand. The twill weave has a highly distinct design with a prominent diagonal line across the cloth, yet the backside has a smooth face with an opposing design. (Adanur, 2020).

3.5 Evaluation

Textile material evaluation is a critical activity for textile production, product and process development, research, distribution, and consumption. Evaluation is further categorized in subjective and objective evaluation.

3.5.1 Subjective evaluation

In subjective assessments, it conveys the particular assessor's experience and expertise (Sülar and Okur, 2008). Quality in terms of comfort and aesthetic appearance is subjective; it is determined by each person's uniqueness and other variables. The subjective evaluation was carried to get the opinion from post graduate students in Textiles and clothing Department at Avinashilingam University, Coimbatore-43, in terms of visual and end-use preference.

3.5.1.1 Visual Evaluation

Twenty post graduate students in Textiles and clothing Department at Avinashilingam University, Coimbatore-43, individually evaluated and ranked each fabric attributes. The criteria for visual evaluation were color, lustre, texture and overall appearance. The Proforrna used for evaluation is given in Appendix II. The scores were collected, consolidated and presented in the chapter in results and discussion.

3.5.1.2 Suggestions for Product Preferences of Woven Samples for End Uses

Twenty post graduate students in Textiles and clothing Department at Avinashilingam University, Coimbatore-43, individually evaluated and ranked end uses. The criteria for end-use applications were apparel, home textiles, accessories and others. The Proforrna used for evaluation is given in Appendix III. The scores were collected, consolidated and presented in the chapter in results and discussion and the results ie., the opinion is carried out for product development.

3.5.2 Objective evaluation

The process of examining, measuring, and assessing the features and properties of textile materials is known as textile testing. The prepared fabric sample was objectively analysed for various tests namely, Fabric weight, Thickness, Stiffness, Drape, Dimensional stability, Fabric count, Crease recovery, Tensile strength, Tear strength, Abrasion, Air permeability, Drop, Wicking, Sinking (50ml), Spray test.

3.5.2.1 Physical tests

The physical tests include fabric weight, fabric thickness, fabric stiffness, drapabilitty, dimensional stability and fabric count. The samples were preconditioned as per ASTM D 1776 practice.

3.5.2.1.1 Fabric weight

A fabric's weight is calculated by its "mass per unit area" or "mass per unit length." To produce uniform specimen size, templates are used to capture specimens of predetermined dimensions. The most common standard measure is grams per square metre (g/m^2) (Wang, X., 2008).

The fabric weight tests were taken as directed in ASTM test method D 3776 option C - 2002. The samples from the fabric were cut randomly for testing. The samples were preconditioned as directed in practice ASTM D 1776. A GSM die cutter was used to cut the samples. The area of the circular GSM die cutter is 100 cm^2. The samples were weighed in an electronic balance. The weight of the sample was measured in grams and multiplied into 100 to get the Grams per Square Meter value. The same procedure was followed for all the samples. Ten samples were tested and the average was calculated (Islam and Haque, 2014).

3.5.2.1.2 Fabric thickness

The thickness of a compressible material, such as a textile fabric, is determined by precisely measuring the distance between two plane parallel plates separated by the cloth. Fabric thickness was determined in accordance with test method ASTM D 1777-2002. The samples were preconditioned as specified in practice ASTM D 1776.

The thickness tester from Hungary was utilized. It was made up of two parts: the anvil and the pressure foot, which functioned together via a level spring action. A dial at the top displayed the thickness of the sample in thousandths of an inch. Loading weight 4.14 kPa was utilized while inserting the fabric between the plates. Each FBI division of the dial read 0.01mm. The sample was put on the anvil plate, and the pressure foot's lever was gently released, allowing the presser foot to press the sample. The thickness of the sample was displayed by the dial. The mean of ten readings gathered from different locations in the sample was computed (Shimo, 2017).

3.5.2.1.3 Fabric Stiffness

The stiffness of a fabric is a unique feature. The bending length is a measurement of the relationship between fabric weight and stiffness, as demonstrated by how the fabric bends under its own weight (Basu, 2006).

As specified in ASTM D 1776, the samples were conditioned in the standard environment. The bending length and flexural rigidity of the cloth were assessed using ASTM test method D 1388 - 2002. The stiffness of the samples was determined using Shirley Stiffness tester. The sample was trimmed to the template size, and both the template and the sample were then transferred to the platforrn with the material below. Both were moved forward gradually. The material strip began to fall over the edge of the platform, and the movement of the template and the sample was observed until the tip of the sample shown in the mirror cut both index lines. The blending length was quickly read from the scale opposite the zero line, which was inscribed on the sides of platform. Sample was examined ten times, at warp and weft of the fabric. Mean values for bending length in warp and weft were computed.

3.5.2.1.4 Drapability test

The term drape refers to how a cloth hangs when it is supported by its own weight. The purpose of measuring a cloth drape is to determine its capacity to hang in lovely curves (Saville, 2002).

The Eureka Drapemetre was used for characterizing the draping properties of fabrics. A brown paper of 31 cm diameter was cut using a template and weighed (F). A circular sample of the same size was cut using the template and was draped over a disc of 18 cm diameter. A light source and lens located below the disc projected image of the draped sample on the brown paper, which was placed over the glass lid. The outline of the projected image was carefully traced out. The paper was cut along this outline and weighed (Wpa). The area of the supporting disc was cut away from the actual projected area and then weighed again (Wsda) (Fan and Hunter, 2009). The drape coefficient percentage was calculated using the formula

$$\mathbf{F} = \frac{\mathrm{Wpa} - \mathrm{Wsda}}{\mathrm{P}} \mathbf{X\ 100}$$

Where, F = Drape co-efficient percentage P = Weight of annular ring of paper Wpa = Weight of the projected area of paper and Wsda = Weight of the supporting disc area of the paper.

3.5.2.1.5 Dimensional Stability

Dimensional change is defined as change in length or breadth of a fabric specimen. The samples were conditioned in standard atmosphere, as specified in AATCC test method 135-2004. Five pairs of bench markings 25 cm long were marked with thread in the warp and weft directions, 12 cm apart and not less than 5 cm from the test edge of sample. The indicated samples were washed in an automated washing machine with the regular detergent at a temperature of 27°C. After the last spin cycle, the sample was taken and dried on a line. The dimensional stability was determined by employing the formula:

$$\textbf{Dimensional Change (DC)} = \frac{B-A}{A} \times 100$$

Where, A = Original dimension; B = Dimension after laundering

3.5.2.1.6 Fabric Count

The fabric count is the number of warp and weft strands per unit distance while the fabric is maintained taut and wrinkle-free. The fabric samples were analyzed according to ASTM 3775-2003 test procedure. Fabric is preconditioned according to D 1776 directed that the textiles be preconditioned. The fabric count of all the samples was determined using a pick glass with a magnifying lens.

3.5.2.2 Mechanical tests

The mechanical test for the sample includes: crease recovery and tensile strength.

3.5.2.2.1 Crease Recovery

The capacity of a fabric to resist creasing is initially determined by the type of fibre used in its production. Crease recovery is usually expressed in terms of degrees and it is associated in part with fabric stiffness (Choudhury, 2017).

Shirley Crease Recovery Tester was used for the study. The instrument consists of a circular dial which carries the clamp for holding the sample. Directly under the centre of the dial is a knife edge and an index line for measuring the recovery angle. A specimen was cut from the fabric with a template, 2" long by 1" wide. It was carefully creased by folding in half, placing it between two glass plates, and adding a 2 kg weight. After one minute the weight was removed and the specimen transferred to the fabric clamp on the instrument and allowed to recover from the crease. As it recovers, the dial of the instrument was rotated to keep the free edge of the specimen in line with the knife edge. At the end of the time period allowed for recovery, usually one minute, the recovery angle in degrees was read on the engraved scale.

3.5.2.2.2 Tensile Strength

The capacity of a material to resist a pulling (tensile) force is known as tensile strength. It is generally expressed as a force per cross-sectional area. Tensile strength of a cloth is expressed as an extreme load that it would tolerate deprived of breaking when exposed to uniaxial tensile load (Rathinamoorthy, 2020).

As specified in ASTM D 1776, the samples were conditioned in the standard environment. The bending length and flexural rigidity of the cloth were assessed using ASTM test method D 1388 - 2002.

The magnitude of stretching force at which the fabric begins to break when strained is known as the tensile strength of the fabric. The force is expressed in Newtons, pounds, or kilograms. It varies according to yarn strength, the fabric type, and the thread count per square inch of the cloth, among other factors. The fabric's tensile strength is measured individually in the warp and weft directions. Each sample was 25 cm in length and 5 cm in width. Ten readings were taken for each material and the mean value was calculated.

3.5.2.3 Comfort test

Comfort is a qualitative concept that is an important feature of any textile material. The comfort properties of a fabric are mostly determined by its structure and the type of yarn used (Das & Ishtiaque, 2004). The air permeability of the fabric was tested.

3.5.2.3.1 Air Permeability

The velocity of air flow perpendicularly travelling through a known area of fabric is regulated to provide a specified air pressure difference between the two fabric surfaces (Rosace, 2017)The fabric is preconditioned according to ASTM 1776 standard. ASTM D 737 testing standard is used to test the air permeability of given fabric. The area of the test was 38cm^2 with air pressure 125Pa.

This test method covers the measurement of the air permeability which is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of of textile fabrics and is applicable to woven fabrics and many others. It is generally expressed in SI units as cm^3/s/cm^2 and in inch-pound units as ft^3/min/ft^2.

3.5.2.4 Absorbency

Absorbency tests include drop test, wicking test, sinking test and spray rating test.

3.5.2.4.1 Drop Test

The drop test is a test that instantly determines if a fabric is absorbent or not. The conditioned cloth was laid over an embroidery hoop without creases and kept 9.5 mm below a burette positioned to give 15 - 25 droplets of water per milliliter, according to the AATCC 2008. A drop of distilled water was dropped on the fabric. The stop watch was immediately started, and the time it took for the drop of water to lose its stunning reflectivity and appear as a dull wet spot was recorded in seconds. Ten readings were taken; the shorter the average duration, the more absorbent is the cloth.

3.5.2.4.2 Wicking Test

In this experiment, a strip of cloth is suspended lengthwise with its lower edge in a pool of distilled water. The pace of movement of the leading edge of the water is then observed. A dye is applied to the water to determine the location of the water line. The measured height of rise in a given time is viewed as a direct indication of the test wickability of the fabric. The higher the wicking distance, the better the fabric is in wicking.

3.5.2.4.3 Sinking Test

The sinking time test determines how long it takes for a test specimen to be completely soaked by water when lying on water's surface. A 25mm X 25mm piece of cloth cut from the fabric is placed over the top of distilled water and the time it takes to sink is measured. A 50 ml beaker is filled with distilled water. The sample is dropped from a regular height onto the water's surface. The stop watch is started when the fabric touches the water surface and stopped only when last corner went below the water's surface, with the time taken to sink the sample recorded in seconds. Ten similar measurements are obtained, and the mean value for all ten samples is computed.

3.5.2.4.4 Spray Rating Test

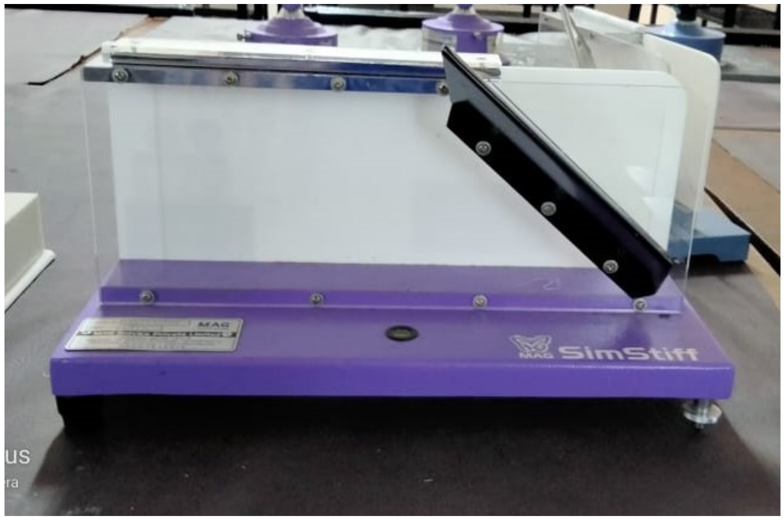
The Spray Rate Test is a test to determine the water repellency of materials using a 'shower test'. The spray rating test is used to determine a fabric's resistance to surface wetting but not to water penetration. In the test, sample is held tight over a 150mm diameter embroidery hoop positioned at 45° to the horizontal. A funnel with a standard nozzle and 19 perforations of a certain diameter is held 150mm above the cloth surface. 250ml of distilled water is put into the funnel to provide a constant spray on the fabric. After the water spray has stopped, the hoop and specimen are removed and sharply tapped twice against a solid object on opposite points of the frame, with the cloth remained horizontal. This eliminates any huge drops of water. The fabric is then given a spray rating.

PLATE V

FABRIC WEIGHT

PLATE VI

FABRIC THICKNESS



PALTE VII

FABRIC STIFFNESS

PLATE VIII

DRAPE TEST

PLATE IX

TENSILE STRENGTH

PLATE X

CREASE RECOEVRY

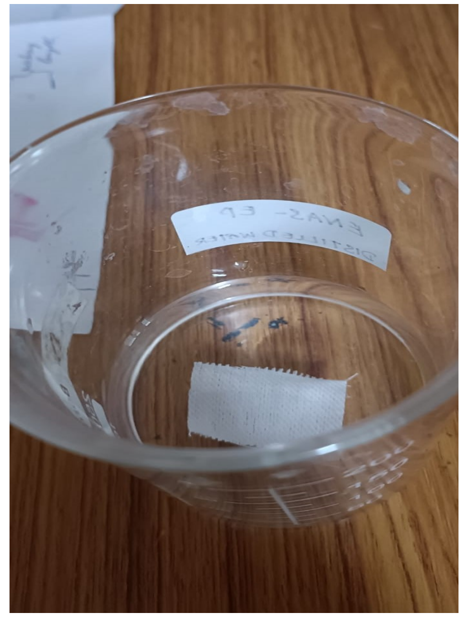


PLATE XI

SINKING TEST

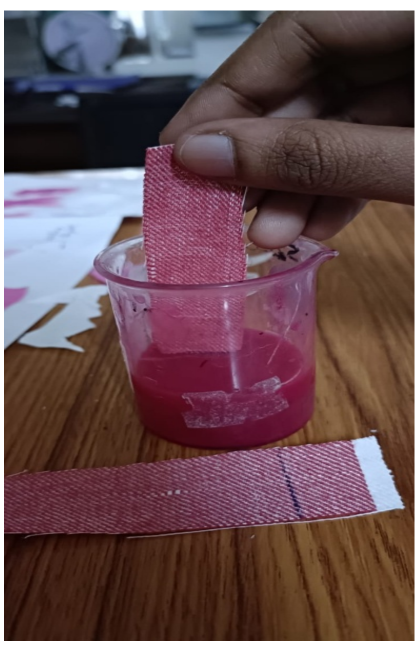


PLATE XII

WICKING TEST

PLATE XIII

SPRAY RATINGTEST

3.6 Product Development

Product development is critical to the long-term viability of any industry. This study presents a beneficial viewpoint for recycled fibres obtained from textile waste by blending it with other fibre and applying it in appropriate. Many attempts are now being made to decrease the environmental impact of textile production.

Hand-woven fabric produced from the blend of recycled cotton and hemp can find its use in various applications which includes textile and apparel, home textiles, and accessories. The developed fabric is durable and has greater life duration and can withstand wear and tear. Hence, it was selected for developing a laptop bag.

A laptop sleeve, sometimes also known as a laptop bag, is bag/pouch made of textile material that is slightly bigger than the laptop and meant to protect it from knocks, scratches, wetness, and dust in normal usage.

3.6.1 Construction of laptop bag

Requirements:

- Constructed fabric
- Inner lining and sponge to provide firmness
- Zipper

- The laptop dimension was measured initially.
- The original fabric was cut according to the preferred laptop size.
- Then two rectangles of the inner lining were cut and attached with the fabric.
- Cut out four stripes of original fabric: 2 cm wide and 20 cm long with rounded corners on both sides.
- Both ends of the long thin fabric strip attached to the ends of the zipper, the seam allowance towards the fabric was folded.
- The finished long thin fabric strip was attached to the rectangular piece of original fabric.
- In- set pocket was attached.
- Zipper was attached to the rectangular piece and the pocket and finished accordingly.

- Bag was finished with addition of handles.
- Extra threads were trimmed to give neat appearance.

3.7 Statistical Analysis

The results of laboratory tests were analyzed statistically using univariate analysis for descriptive study. The collected data was organized, tabulated, analyzed and interpreted by using univaritate statistics. Univariate analysis involves the examination across cases of one variable at a time.

RESULTS AND DISCUSSIONS

4. RESULTS AND DISCUSSIONS

Results are defined as “analysis” as the categorizing, ordering, manipulating and summarizing of the data to obtain an answer to a research question. The purpose of analysis is to reduce to an intelligible and interpretable form so that; the relations of research problems can be studied and tested.The results of the study on “**Development of Sustainable Woven Fabric Produced from Recycled Cotton and Hemp**”, presented in Results and Discussions are as follows:

4.1 Subjective Evaluation

4.1.1 Visual Inspection

4.1.2 Suggestions for Product Preferences of Woven Sample for End Uses

4.2 Objective Evaluation

4.2.1 Physical Property

4.2.1.1 Fabric Weight

4.2.1.2 Fabric Thickness

4.2.1.3 Fabric Stiffness

4.2.1.4 Drapability

4.2.1.5 Dimensional Stability

4.2.1.6 Fabric Count

4.2.2 Mechanical Property

4.2.2.1 Crease Recovery

4.2.2.2 Tensile Strength

4.2.3 Comfort Property

4.2.3.1 Air Permeability

4.2.4 Absorbency Property

4.2.4.1 Drop Test

4.2.4.2 Wicking Test

4.2.4.3 Sinking Test

4.2.4.4 Spray Test Rating

4.3 Product Development

4.3.1 Final Product

4.1 Subjective Evaluation

4.1.1 Visual Inspection

Fifty post graduate students in Textiles and clothing Department at Avinashilingam University, Coimbatore-43, individually evaluated and ranked each fabric attributes. The criteria for visual evaluation were color, texture and overall appearance.

TABLE – I

VISUAL INSPECTION

Sample	Rating In Percentage								
	Color			Texture			Overall Appearance		
	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
	85	13	2	90	10	-	93	7	-

From Table - I, it is evident that the majority of the participants ranked 85% of sample as good in color. Ninety percent ranked sample as good in texture, while remaining 10% evaluated fabric with fair texture. Then with regard to overall appearance of the fabric, ninety three percent graded it as fabric with overall good appearance.

4.1.2 Suggestions for Product Preferences of Woven Sample for End Uses

Fifty post graduate students in Textiles and clothing Department at Avinashilingam University, Coimbatore-43, individually evaluated and ranked each fabric attributes. The criteria for end - use evaluation included apparels, home textiles, functional accessories, fashion accessories and all of these.

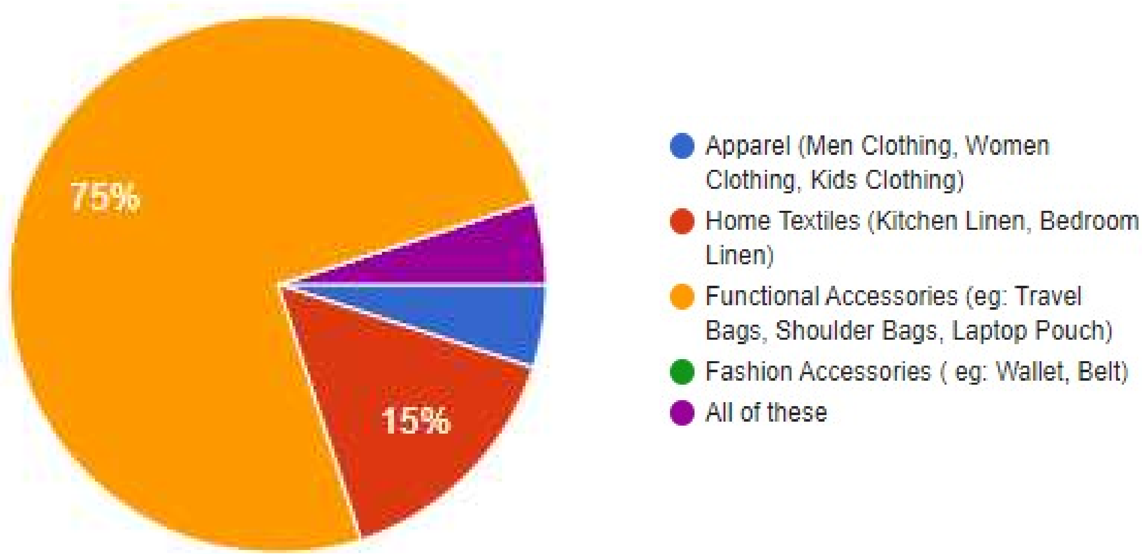


FIGURE - III

Product Preferences of Woven Sample for End Uses

From Figure - III, it is evident that the majority of the participants ranked 75 percent of sample as suitable for functional accessories such as bags. Then with regard to fabric being appropriate for home textiles it was graded by 15 percent. 5 percent ranked sample as appropriate for apparels and for all applications.

4.2 Objective Evaluation

4.2.1 Physical Property

The physical property evaluated for the fabric includes: Fabric Weight, Fabric Thickness, Fabric Stiffness, Drapability, Dimensional Stability and Fabric Count.

4.2.1.1 Fabric Weight

The univariate analysis of descriptive study was carried out and shown in Table – II.

TABLE - II

FABRIC WEIGHT TEST

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Fabric Weight (GSM)	209.8	3.048	9.29	205	214	9

From Table II, it is evident that mean value of fabric weight is 209.8GSM, with the minimum and maximum value of 205 GSM and 214 GSM respectively.

The standard deviation also proved that approximately 95% of values fall in the range of 206.8 GSM to 212.8 GSM. As a conclusion, the statistical distributions of fabric weight values were proven.

4.2.1.2 Fabric Thickness

The univariate analysis of descriptive study was carried out and shown in Table – III.

TABLE - III

FABRIC THICKNESS TEST

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Fabric Thickness (mm)	0.6135	0.0441	0.002	0.55	0.68	0.13

From Table III, it is evident that the sample mean value of thickness is 0.6135mm, with the minimum and maximum value of 0.55mm and 0.68mm respectively.

The standard deviation also proved that approximately 95% of values fall in the range of 0.57mm to 0.65mm. Hence, the distributions of fabric thickness values were statistically proved.

4.2.1.3 Fabric Stiffness

The univariate analysis of descriptive study was carried out and shown in Table – IV.

TABLE - IV

FABRIC STIFFNESS TEST

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Fabric Stiffness (warp)(cm)	1.045	0.178	0.0319	0.75	1.4	0.65
Fabric Stiffness (weft) (cm)	2.05	0.310	0.096	1.5	2.5	1

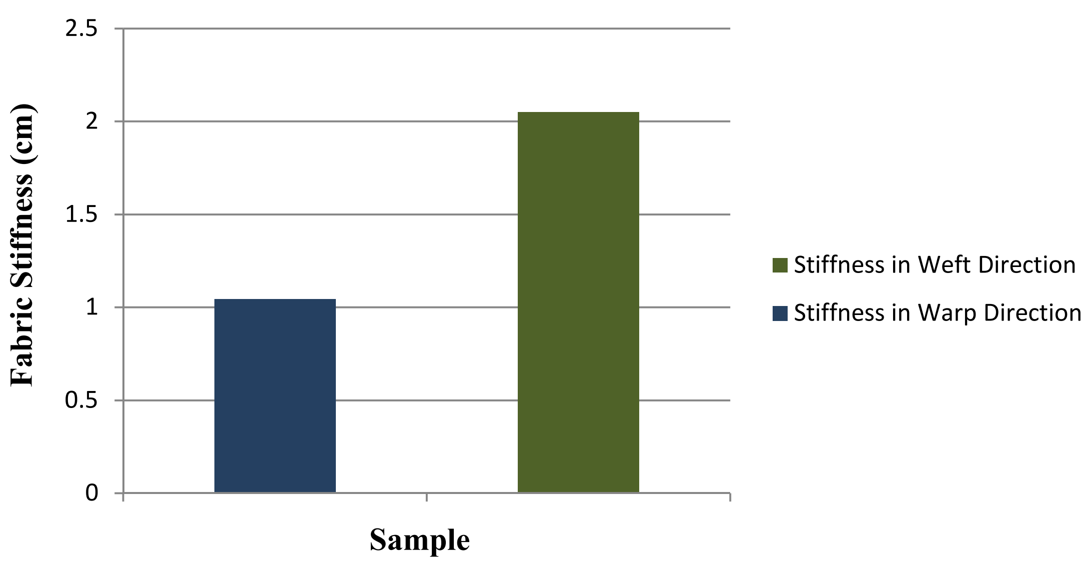


FIGURE - IV

FABRIC STIFFNESS TEST

From Table IV and Figure IV, it is evident that the mean bending length (c) of warp is 1.045 cm, whereas the mean bending length of weft is 2.05 cm, with minimum and maximum values of 0.75 cm and 1.4 cm at warp; 1.5cm and 2.5cm at weft respectively.

The standard deviation also revealed that about 95 percent of results lie between 0.87 cm to 1.22 cm at warp and 1.74 to 2.36 at weft. Hence, the distributions of fabric stiffness values were statistically proved.

Flexural rigidity (G) was obtained by the relation between GSM and bending length. The obtained flexural rigidity at warp was 239.4 mg-cm, while at weft it was 1087 mg-cm.

4.2.1.4 Drapability Test

The univariate analysis of descriptive study was carried out and shown in Table – V.

TABLE - V

DRAPABILITY TEST

Sample	Mean (%)	Standard deviation	Variance	Minimum	Maximum	Range
Drape coefficient (%)	38.402	1.692	2.864	36	41.5	5.5

From Table V, it is evident that the mean drape coefficient obtained is 38.402%, with the minimum and maximum value of 36% and 41.5% respectively.

The standard deviation also demonstrated that about 95 percent of results lie between 37 and 40%. Hence, the distributions of drapability test values were statistically proved.

4.2.1.5 Dimensional Stability

The univariate analysis of descriptive study was carried out and shown in Table – VI.

TABLE - VI

DIMENSIONAL STABILITY

DIMENSIONAL STABILITY (%)	
Warp	- 2.65%
Weft	- 4.16%

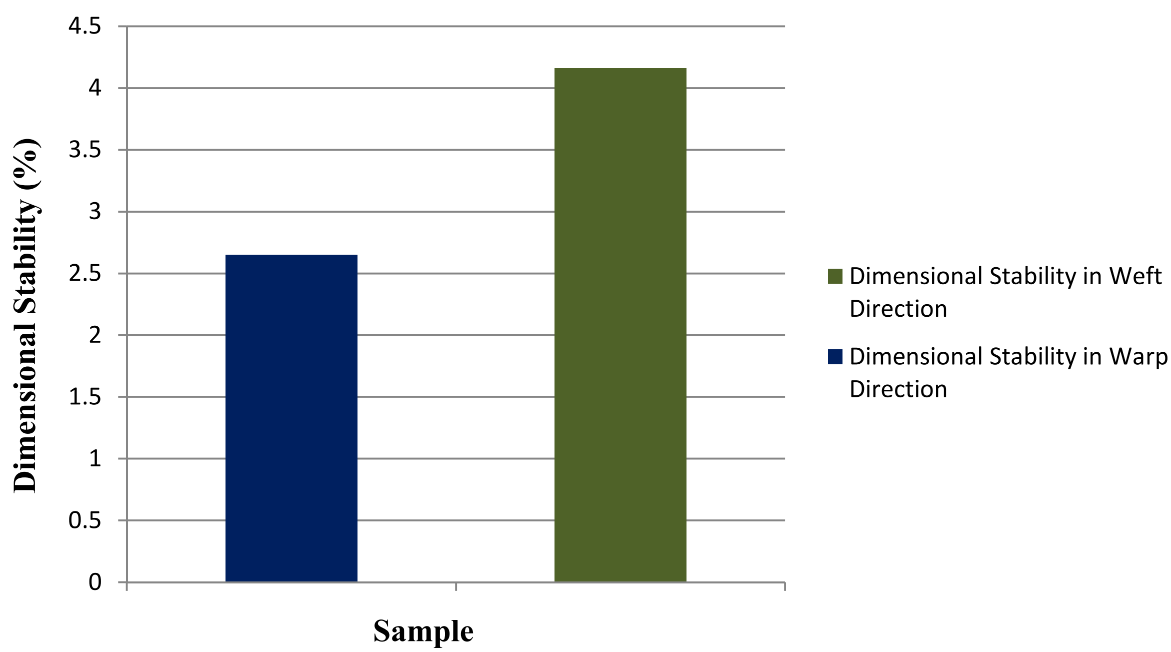


FIGURE V

DIMENSIONAL STABILITY

From Table VI and Figure V it is clear that shrinkage was seen on the fabric in both warp and weft at 2.65% and 4.16% respectively. The shrinkage was higher in weft in comparison to warp yarn.

4.2.1.6 Fabric Count

The univariate analysis of descriptive study was carried out and shown in Table – VII.

TABLE - VII

FABRIC COUNT

Sample	Yarn count	Warp cover factor	Weft cover factor	Cloth cover factor
Fabric count	20s	13.41	12.52	20

From Table VII, it is evident that the sample with yarn count of 20s has warp cover factor of 13.41 and weft cover factor of 12.52. Cloth cover factor was obtained using the formula of warp and weft count factor as 20.

4.2.2 Mechanical Property

The mechanical property tests include: crease recovery and tensile strength

4.2.2.1 Crease Recovery

The univariate analysis of descriptive study was carried out and shown in Table – VIII

TABLE - VIII

CREASE RECOVERY

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Crease Recovery (%)	94.7	1.89	3.56	92	98	6

From Table VIII, it is evident that the mean value of crease recovery is 94.7%, with the minimum and maximum value of 92% and 98% respectively.

The standard deviation also demonstrated that about 95 percent of results lie between 92.8% and 96.6%. Hence, the distributions of crease recovery values were statistically proved.

4.2.2.2 Tensile Strength and Elongation

The univariate analysis of descriptive study was carried out and shown in Table – IX.

TABLE – IX

TENSILE STRENGTH

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Fabric Tensile Strength (warp) (lb) (dry)	88.50	7.34	53.83	76	98	22
Fabric Tensile Strength (weft) (lb) (dry)	160	25.83	667.33	130	200	70
Fabric Tensile Strength (warp) (kg) (wet)	154.2	3.084	9.51	148	158	10
Fabric Tensile Strength (weft) (kg) (wet)	225.8	2.34	5.511	222	230	8

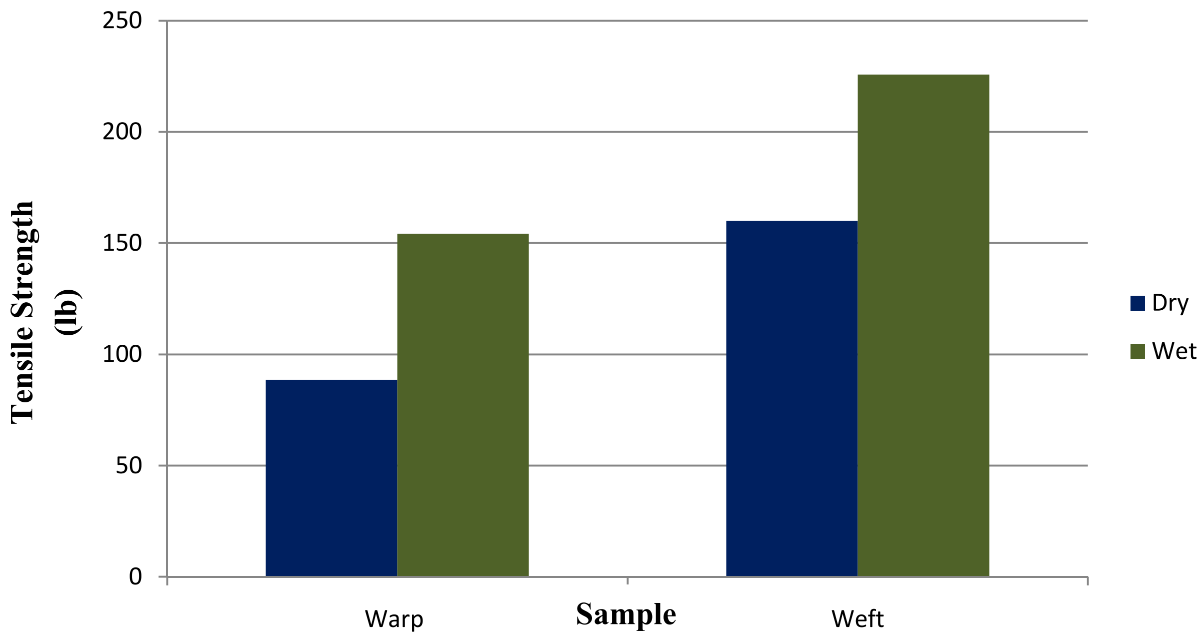


FIGURE – VI

TENSILE STRENGTH

From Table IX and Figure VI, it is evident that the mean tensile strength of warp at dry state is 88.5lb, whereas the mean tensile strength of weft at dry state is 160 lb, with minimum and maximum values of 76lb and 98lb at warp and 130lb and 200lb at weft respectively.

The standard deviation also revealed that about 95 percent of results lie between 81.2lb and 95.8lb at warp in dry state and 134.2lb to 185.8lb at weft in dry state. Hence, the distributions of tensile strength values were statistically proved.

The mean tensile strength of warp at wet state is 154.2lb, whereas the mean tensile strength of weft at wet state is 225.8 lb, with minimum and maximum values of 148lb and 158lb at warp in wet state and 222lb and 230lb at weft in wet state respectively.

The standard deviation also revealed that about 95 percent of results lie between 151.11lb and 157.28lb at warp in wet state and 223.46lb to 228.14lb at weft in wet state. Hence, the distributions of tensile strength values were statistically proved.

TABLE X

ELONGATION

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Elongation warp dry(inch)	2.04	0.1349	0.0182	1.8	2.2	0.4
Elongation weft dry (inch)	2.375	0.184	0.034	2	2.6	0.6
Elongation warp wet inch)	2.61	0.179	0.032	2.3	2.9	0.6
Elongation weft wet (inch)	3.11	0.126	0.016	2.9	3.25	0.35

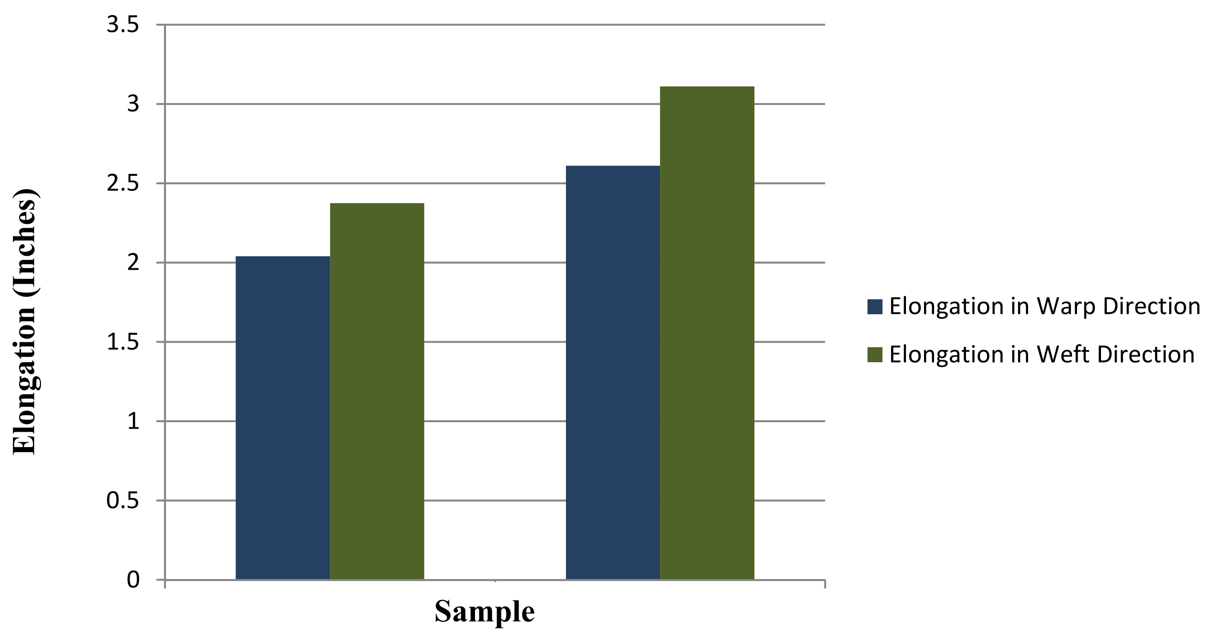


FIGURE – VII

ELONGATION

From Table X and Figure VII, it is evident that the mean elongation of warp at dry state is 2.04inches, whereas the mean tensile strength of weft at dry state is 2.375inches, with minimum and maximum values of 76lb and 98lb at warp and 1.8 and 2.2imch at weft respectively.

The mean tensile strength of warp at wet state is 2.61inches, whereas the mean tensile strength of weft at wet state is 3.11inches, with minimum and maximum values of 2.3 and 2.9 at warp in wet state and 2.9 and 3.25 inch at weft in wet state respectively.

The elongation percent of warp at dry state is 20.4%, whereas the elongation of weft at dry state is 23.75% The elongation of warp at wet state is 26.1%, whereas the elongation of weft at wet state is 31.1%.

4.2.3 Comfort Property

4.2.3.1 Air Permeability

Air permeability is a desirable characteristic that affects the comfort offered by the fabric. Table X indicates the air permeability of the fabric.

TABLE – XI

AIR PERMEABILITY TEST

Sample	Air permeability ($cm^3/cm^2/s$)	C.V (%)
R-C-H	65.3	3.4

From Table XI, it is evident that at testing pressure of 125Pa, in unit area of 38 cm^2, 65.3 cm^3 air can pass through the fabric.

4.2.4 Absorbency

Absorbency test include drop test, wicking test, sinking test and spray rating test.

4.2.4.1 Drop Test

The univariate analysis of descriptive study was carried out and shown in Table – XI.

TABLE – XII

DROP TEST

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Fabric Drop Test (sec)	0.85	0.21	0.04	0.6	1.1	0.5

From Table XII, it is evident that the mean value of drop test is 0.85seconds, with the minimum and maximum value of 0.6seconds and 1.1seconds respectively.

The standard deviation also demonstrated that about 95 percent of results lie between 0.65 seconds and 1.06 seconds. Hence, the distributions of drop test values were statistically proved.

4.2.4.2 Wicking Test

The univariate analysis of descriptive study was carried out and shown in Table – XII.

TABLE – XIII

WICKING TEST

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Wicking (cm)	1.54	0.24	0.06	1.2	2.0	0.8

From Table XIII, it is evident that the mean value of wicking test is 1.54cm, with the minimum and maximum value of 1.2cm and 2cm respectively.

The standard deviation also demonstrated that about 95 percent of results lie between 1.30cm and 1.78cm. Hence, the distributions of wicking test values were statistically proved.

4.2.3.4 Sinking Test

The univariate analysis of descriptive study was carried out and shown in Table – XIII.

TABLE – XIV

SINKING TEST

Sample	Mean	Standard deviation	Variance	Minimum	Maximum	Range
Sinking (sec)	1.59	0.37	0.14	1.11	2.05	0.94

The fabric swatches were dropped in 50ml of water and the time taken to sink is noted. From the Table XIVI, it is evident that the mean value of sinking test is 1minute and 59seconds, with the minimum and maximum value of 1minute 11seconds and 2minutes 5seconds respectively. The standard deviation also demonstrated that about 95 percent of results lie between 1.22minutes and 1.96minutes. Hence, the distributions of sinking test values were statistically proved. Since, the time taken to sink at bottom of water is more than 1 minute, the fabric is considered to float.

4.2.3.5 Spray Rating Test

Spray rating test of fabric follows AATCC 22 standard. The tested fabric value is matched with the standard scale. Hence, the water rating of fabric is 70 - partial wetting of whole of upper surface of fabric is observed as shown in Plate XIV.

PLATE XIV

SPRAY RATING TEST

4.3 Product Development

4.3.1 Final Product

Laptop bags are a tiny yet, simple solution to protect a laptop without the need to carry a bigger, more typical laptop bag. A laptop in its sleeve can then fit into another carry bag, reducing the requirement for two bags. Laptop sleeves are also viewed as a fashion element that may enhance an overall look of an individual being.

PLATE XV

FINAL PRODUCT

SUMMARY AND CONCLUSSION

5. SUMMARY AND CONCLUSIONS

The textile and clothing sector is one of the oldest and most well-known industries. It is one of the oldest businesses and has a legendary reputation. The textile sector is vast and capable of generating tones of textile product each year. However, it is one of the world's most unsustainable sectors, both in terms of the environment and of social concerns. It necessitates the employment of indefinite chemicals not only from the beginning of textile manufacturing to the finishing processes, but also in crop cultivation for commercial purposes.

Clothing is often thrown in large quantities, ending up in landfills and contributing to the environmental disaster. The tendency of "fast fashion" has been heavily condemned for depleting environmental resources and contributing to environmental catastrophe (Jung and Jin, 2016). Not only do fast fashion corporations hurt the environment, but so do customers in a variety of ways. Fast fashion is sometimes referred to as 'disposable fashion' due to its qualities (Young Lee, Halter, Johnson & Ju 2013; Morgan & Birtwistle 2009). Fast fashion has made mass production of clothes much easier and cheaper, leading to excessive purchase and demand of garments, which in turn results in generation of poor quality clothes which are harmful to the environment.

Meeting human needs without overburdening the environment or society is referred to as sustainability. The increased awareness of the environmental damage caused by synthetic materials has aided in the development of eco-friendly materials. Researchers have shown a keen interest in developing such materials that can replace synthetic materials. Textile waste may be up-cycled or recycled into new and useful goods.

Cotton is the bedrock of the worldwide textile industry. Cotton is employed in many of our everyday textile materials because to its physical and chemical qualities, and its usage in close proximity to humans. Cotton is one of the most frequently produced natural fibres, imposing substantial use of water and chemicals (such as pesticides and fertilisers). Recycling textile waste is a viable solution to many problems associated with growing landfills, as well as reducing the quantity of water and chemicals required in fibre manufacturing from the start. Therefore, recycled cotton is an environmentally beneficial fabric alternative to conventional cotton and organic cotton.

Hemp is a high-quality fibre. Hemp fibre is a fine, light-colored, glossy, and strong bast fibre obtained from the hemp plant. Hemp fibres offer various advantages over other fibres that set them distinct. These are more absorbent, stronger, provide UV protection, and have no allergic reactions (Kostic et al., 2008). Hemp farming also requires less water and uses little or no chemicals. Hemp fibre is several times stronger than cotton fibre and is often considered as the world's longest, strongest, and longest-lasting fibre (Müssig et al., 2020).

Based on the above background and information the following objectives were proposed for the thesis entitled **"Development and Evaluation of Sustainable Woven Fabric Produced from Recycled Cotton and Hemp":**

- To select the raw material: recycled cotton and hemp yarn.
- To prepare fabric using suitable fabrication method and to prepare sample.
- To evaluate subjective and objective quality parameters.
- To design and develop a suitable end product.

Recycled cotton and hemp yarn of count 20s were selected as raw materials for this study. Weaving was carried out by using the selected material in pit loom, 2x2 twill weave structure was implemented to produce fabric of 5 m long and 15 inch width. The fabric was then evaluated in both subjective and objective quality parameters.

Findings of the study

Subjective evaluation

The subjective evaluation was carried to get the opinion from fifty post graduate students in Textiles and clothing Department at Avinashilingam University, Coimbatore-43, in terms of visual and end-use preference.

Visual inspection

Fifty post graduate students in Textiles and clothing Department at Avinashilingam University, Coimbatore-43, individually evaluated and ranked each fabric attributes. The criteria for visual evaluation were color, texture and overall appearance.

According to visual inspection, majority of the participants ranked 85% of sample as good in color. Ninety percent ranked sample as good in texture, while remaining 10% evaluated it as fabric with fair texture. Then with regard to overall appearance of the fabric, ninety three percent graded it as fabric with overall good appearance.

Suggestions for Product Preferences of Woven Samples for End Uses

Fifty post graduate students in Textiles and clothing Department at Avinashilingam University, Coimbatore-43, individually evaluated and ranked each fabric attributes. The criteria for end - use evaluation included apparels, home textiles, functional accessories, fashion accessories and all of these.

The majority of the participants ranked 75 percent of sample as suitable for functional accessories such as bags. Then with regard to fabric being appropriate for home textiles it was graded by 15 percent. 5 percent ranked sample as appropriate for apparels and for all applications.

Objective evaluation

- **Fabric weight**

The fabric weight tests were taken as directed in ASTM test method D 3776. The mean value of fabric weight is 209.8GSM, with the minimum and maximum value of 205 GSM and 214 GSM respectively. The standard deviation also proved that approximately 95% of values fall in the range of 206.8 GSM to 212.8 GSM. As a conclusion, the statistical distributions of fabric weight values were proven.

- **Fabric thickness**

Fabric thickness was determined in accordance with test method ASTM D 1777 the sample mean value of thickness is 0.6135mm, with the minimum and maximum value of 0.55mm and 0.68 mm respectively. The standard deviation also proved that approximately 95% of values fall in the range of 0.57mm to 0.65mm. Hence, the distributions of fabric thickness values were statistically proved.

- **Fabric stiffness**

Fabric stiffness of the cloth was assessed using ASTM test method D 1388. The mean bending length (c) of warp is 1.045 cm, whereas the mean bending length of weft is2.05 cm, with minimum and maximum values of 0.75 cm and 1.4 cm at warp; 1.5cm and 2.5cm at weft respectively. The standard deviation also revealed that about 95 percent of results lie between 0.87 cm to 1.22 cm at warp and 1.74 to 2.36 at weft. Hence, the distributions of fabric stiffness values were statistically proved. Flexural rigidity (G) was acheived by the relation between GSM and bending length. The obtained flexural rigidity at warp was 239.4 mg-cm, while at weft it was 1087 mg-cm.

- **Drapability test**

The mean drape coefficient obtained is 38.402%, with the minimum and maximum value of 36% and 41.5% respectively. The standard deviation also demonstrated that about 95 percent of results lie between 37 and 40%. Hence, the distributions of drapability test values were statistically proved.

- **Dimnesional stability**

The fabric weight tests were taken as directed in AATCC 135 test method. It was observed that there was shrinkage was seen on the fabric in both warp and weft at 2.65% and 4.16% respectively. The shrinkage was higher in weft in comparison to warp yarn.

- **Fabric count**

The fabric samples were analyzed according to ASTM 3775 test procedure. the sample with yarn count of 20s has warp cover factor of 13.41 and weft cover factor of 12.52. Cloth cover factor was obtained using the formula of warp and weft count factor as 20.

- **Crease recovery**

The fabric weight tests were taken as directed in AATCC 66 test method. The mean value of crease recovery is 94.7%, with the minimum and maximum value of 92% and 98 % respectively. The standard deviation also demonstrated that about 95 percent of results lie between 92.8% and 96.6%. Hence, the distributions of crease recovery values were statistically proved.

- **Tensile strength and Elongation**

The mean tensile strength of warp at dry state is 88.5lb, whereas the mean tensile strength of weft at dry state is 160 lb, with minimum and maximum values of 76lb and 98lb at warp and 130lb and 200lb at weft respectively. The standard deviation also revealed that about 95 percent of results lie between 81.2lb and 95.8lb at warp in dry state and 134.2lb to 185.8lb at weft in dry state. Hence, the distributions of tensile strength values were statistically proved.

The mean tensile strength of warp at wet state is 154.2lb, whereas the mean tensile strength of weft at wet state is 225.8 lb, with minimum and maximum values of 148lb and 158lb at warp in wet state and 222lb and 230lb at weft in wet state respectively. The standard deviation also revealed that about 95 percent of results lie between 151.11lb and 157.28lb at warp in wet state and 223.46lb to 228.14lb at weft in wet state. Hence, the distributions of tensile strength values were statistically proved.

The mean elongation of warp at dry state is 2.04inches, whereas the mean tensile strength of weft at dry state is 2.375inches, with minimum and maximum values of 76lb and 98lb at warp and 1.8 and 2.2imch at weft respectively.

The elongation percent of warp at dry state is 20.4%, whereas the mean elongation of weft at dry state is 23.75% The elongation of warp at wet state is 26.1%, whereas the elongation of weft at wet state is 31.1%.

The results proved that weft yarn has greater tensile strength than warp yarn both at wet and dry state; it was observed that when fabric was tested at wet state they showed higher elongation value.

- **Air permeability**

Air permeability is a desirable characteristic that affects the comfort offered by the fabric. . At a testing pressure of 125Pa, in a unit area of 38 cm^2, 65.3 cm^3air can pass through the fabric.

- **Drop test**

The mean value of drop test is 0.85seconds, with the minimum and maximum value of 0.6seconds and 1.1seconds respectively. The standard deviation also demonstrated that about 95 percent of results lie between 0.65 seconds and 1.06 seconds. Hence, the distributions of drop test values were statistically proved.

- **Wicking test**

The mean value of wicking test is 1.54cm, with the minimum and maximum value of 1.2cm and 2cm respectively. The standard deviation also demonstrated that about 95 percent of results lie between 1.30cm and 1.78cm. Hence, the distributions of wicking test values were statistically proved.

- **Sinking test**

  The fabric swatches were dropped in 50ml of water and the time taken to sink is noted. The mean value of sinking test is 1minute and 59seconds, with the minimum and maximum value of 1minute 11seconds and 2minutes 5seconds respectively. The standard deviation also demonstrated that about 95 percent of results lie between 1.22minutes and 1.96minutes. Hence, the distributions of sinking test values were statistically proved. Since, the time taken to sink at bottom of water is more than 1 minute, the fabric is considered to float.

- **Spray rating test**

Spray rating test of fabric follows AATCC 22 standard. The tested fabric value is matched with the standard scale. The spray rating of fabric is 70 - partial wetting of whole of upper surface of fabric is observed.

Conclusion

Sustainability is a challenge of the twenty-first century. Sustainability entails satisfying our own needs without jeopardizing ability of future generation to meet their own needs. With the increased desire to seem good and appealing to the eye, the textile and apparel sector generates tonnes of garments per year. These garments and textiles are frequently discarded in landfills before they reach the lifespan. Recycling comes in useful in situations when consumer textile waste is recycled to be utilised in another fashion, whether for another purpose or converted to virgin fibre.

Natural fibres, such as cotton, are biodegradable and non-toxic to human health; however, this does not always imply that the production and following textile manufacture do not use any chemicals, therefore not fulfilling the goal of a safer, cleaner, and more sustainable environment. Recycled cotton is made from consumer waste, eliminating landfills and lowering environmental effect to some extent.

Hemp is a sustainable substance that is renewable, reusable, and recyclable. Hemp grows well in areas where no herbicides, fungicides, or pesticides are used. As a result, it is chemical-free. Hemp is a natural fabric that uses little water. Hemp fibre is several times stronger than cotton fibre and is often considered as the world's longest, strongest, and most durable fibre.

Hemp has been contaminated by its association with marijuana, a plant responsible for psychotropic drugs. Hemp, on the other hand, lacks the euphoric qualities of marijuana. Hemp has repeatedly demonstrated to be a better alternative for cotton in terms of production and productivity, as well as a smaller potential ecological imprint. It is past time for hemp, as a whole or in blends, to be introduced and used to replace many other synthetic and natural fibres that have a negative impact on the environment in commercial textile production.

A new product concept is a statement about anticipated product attributes that will bring distinct advantages over existing products or challenges. Developing items that are useful in everyday life can boost laypeople's desire and make them aware of the impact of their purchasing decisions on the Earth's ecosystem.

Further Studies:

Recycled cotton may be combined with other fibres in various ratios to produce textiles that can be used in a variety of applications while remaining sustainable. Hemp fibre can be used and explored for a wide range of textile applications, including nonwovens, wovens, knit configurations, and technical textiles, where its inherent natural physical qualities show tremendous promise. Hemp fabrics can be introduced at commercial level.

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APPENDICES

Appendix I

Fabric Swatch

Appendix II

Visual Inspection

Sample	Rating In Percentage								
	Color			Texture			Overall Appearance		
	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor

Appendix III

Suggestions for Product Preferences of Woven Samples for End Uses

"Development of Sustainable Woven Fabric Produced from Recycled Cotton and Hemp":

I, Glory Grace Prasad, student of M.Sc Bio Textiles from Avinashilingam Deemed University, Coimbatore - 641043 would like to conduct survey for research purpose. The responses received will be confidential. I highly appreciate your cooperation.

1. Email *

2. Name *

3. Email Id *

4. Course *

Mark only one oval.

- ◯ M.Sc BioTextiles
- ◯ M.ScTextiles and Fashion Apparel

Subjective Opinion Question

Kindly find the image below for your reference. Choose the best possible option as per your opinion.

5. The fabric formed by blend of recycled cotton and hemp can be used for the *

product development of ____.

Mark only oneoval.

- ◯ Apparel (Men Clothing, Women Clothing, Kids Clothing)
- ◯ Home Textiles (Kitchen Linen, Bedroom Linen)
- ◯ Functional Accessories (eg: Travel Bags, Shoulder Bags, Laptop Pouch)
- ◯ Fashion Accessories (eg: Wallet, Belt)
- ◯ All of these

Appendix IV

PSGTECHS COE INDUTECH LABORATORY

CENTER OF EXCELLENCE FOR INDUSTRIAL & HOME TEXTILES

Promoted by Ministry of Textiles - Government of

INDIAAvinashi Road, Neelambur, Coimbatore-641062

Telephone: 0422 – 3933250 – 252, E-mail: testing.int@psgtech.ac.in

TEST REPORT

REF NO: COE/2022/MAR/9347

Name of the Applicant : S.GLORY GRACE PRASAD.

Avinashilingam University, Cbe.

Receiving Date : 08-03-2022
Tested Date : 10-03-2022
Report Date : 10-03-2022

Sample Description : NA
Type of sample : Woven Fabric

Type of test : Air Permeability.

Results Summary / Conclusion:

Test	Test Method	Remarks
Air permeability	**ASTM D 737**	**Refer Result**

TEST REPORT

REF NO: COE/2022/MAR/ 9347 Report Date: 10-03-2022

R E S U L T S

1. AIR PERMEABILITY: (Test Method-ASTM D 737)Testing Pressure: 125Pa

Testing area : 38 cm^2

Sample Specification	Air Permeability (cm3/cm2/s)	C.V (%)
R-C - H	65.3	3.4

<<< END OF THE TEST REPORT >>>