A STUDY ON FIBRE IDENTIFICATION AND CHARACTERIZATION OF VARIOUS HEADSCARF FABRICS

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A STUDY ON FIBRE IDENTIFICATION AND CHARACTERIZATION OF VARIOUS HEADSCARF FABRICS

by

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CERTIFICATE

This is to clarify that this dissertation, “A Study on Fibre Identification and Characterization of Various Headscarf Fabrics” is bona fide record of research done by Shazwina Ayna Binti Mohd Fahmi during the period of October 2024 to February 2025 under my supervision. I have read this dissertation and that in my point of view it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope, and quality, as a dissertation to be submitted fulfilment for the Bachelor of Science in Forensic Science.

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DECLARATION

I hereby declare that this dissertation is the result of my investigation, except where otherwise cited and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any degrees at Universiti Sains Malaysia or any other institution. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

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(SHAZWINA AYNA BINTI MOHD FAHMI)

Date: 9/2/2025

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LIST OF SYMBOLS

˚C	Degree Celsius
%	Percent
mL	Millilitre
g	Gram

LIST OF ABBREVIATIONS

AATCC	American Association of Textile Chemists and Colorists
DNA	Deoxyribonucleic acid
DMF	Dimethylformamide
DMAc	N, N-dimethylacetamide
FTIR	Fourier transform infrared spectroscopy
FR	Flame retardant
LiCl	Lithium Chloride
LOI	Limiting oxygen index
NaOH	Sodium Hydroxide
PET	Polyethylene terephthalate
SEM	Scanning electron microscope
Temp	Temperature
UV	Ultraviolet

KAJIAN PENGENALPASTIAN DAN PENCIRIAN JENIS GENTIAN PADA PELBAGAI JENIS TUDUNG KEPALA

ABSTRAK

Kajian ini bertujuan untuk mengenalpasti dan mencirikan gentian yang diperolehi daripada enam jenis tudung kepala berasaskan gentian iaitu; kapas, sutera, poliester, *lycra*, *viscose*, dan *moss crepe*, sebagai sumber yang berpotensi dijadikan sebagai bahan bukti dalam penyiasatan forensik. Bukti gentian, yang sering dipindahkan semasa sentuhan fizikal, memainkan peranan penting dalam menghubungkan perkaitan antara suspek, mangsa, dan tempat kejadian. Ujian morfologi mendedahkan bahawa corak anyaman dan struktur benang yang berbeza mempengaruhi sifat gentian, seperti kebolehtelapan dan ketumpatan, yang membantu dapat membantu dalam pembezaan jenis gentian. Kapas dan *viscose* mempunyai corak anyaman biasa, tetapi kapas mempunyai keliangan yang rendah berbanding *viscose*. Poliester dan *lycra* memilik struktur sintetik yang padat, *lycra* memiliki keunikan kerana tidak memiliki manik keras walaupun merupakan serat sintetik. Ujian pembakaran dijalankan bagi mengenal pasti gentian berdasarkan perubahan ketika pembakaran, pembentukan sisa, dan bau yang dihasilkan. Ketika ujian pembakaran dijalankan *moss crepe* dan *viscose* memiliki ciri-ciri yang bercampur kerana kedua-duanya berasal dari sintetik. Ujian kelarutan dijalankan untuk mengesahkan komposisi gentian dengan memerhati reaksi mereka terhadap pelbagai bahan kimia yang menghasilkan perlbagai reaksi terhadap bahan kimia. Keadaan ini turut dipengaruhi oleh struktur kimia dan faktor persekitaran. Kebanyakan gentian tidak larut dalam asid sulfurik 75% dan 60%, dan tiada gentian yang larut dalam asid formik, manakala kebanyakan gentian larut dalam larutan natrium hidroksida 50% pada suhu yang tinggi. Kesimpulannya, kajian ini berjaya mengkelaskan dan mengenal pasti

enam jenis gentian menggunakan kaedah pengenalpastian gentian yang komprehensif, sekali gus meningkatkan nilainya sebagai bukti kesan dalam aplikasi forensik.

A STUDY ON FIBER IDENTIFICATION AND CHARACTERISATION OF VARIOUS HEADSCARF FABRICS

ABSTRACT

This study focuses on the identification and characterisation of fibres from six types of headscarf fabrics, mainly cotton, silk, polyester, lycra, viscose, and moss crepe as potential sources of trace evidence in forensic investigations. Fibre evidence, often transferred during physical contact, plays a crucial role in linking suspects, victims, and crime scenes. Morphological tests revealed that distinct weave patterns and yarn structures significantly influence fabric behaviour, such as porosity and density, aiding in the differentiation of fabric types. Both cotton and viscose exhibited plain weaves, but cotton had a less porous fabric structure than viscose. Polyester and lycra showed dense synthetic structures. Burning tests identified fibres based on their combustion behaviour, residue formation, and odour. Lycra however shows uniqueness in the absence of hard beads although it is synthetic fibre. Moss crepe and viscose displayed mixed traits, confirming their partially synthetic origins. Solubility tests further validated fibre compositions by observing their reactions to various chemical solvents, demonstrating distinct dissolution behaviours influenced by chemical structure and environmental factors. Most fibres did not dissolve in 75% and 60% sulphuric acid, and none dissolved in formic acid, while most fibres dissolved in high-temperature 50% sodium hydroxide solutions. In conclusion, this study successfully classified and identified the six types of fibres using comprehensive fibre identification methods, enhancing their value as trace evidence in forensic applications.

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the realm of forensic science, the intricate relationship between physical evidence and criminal investigations is underscored by Locard's Exchange Principle, which posits that "every contact leaves a trace" (Fuller, 2024). This foundational concept, articulated by Dr. Edmond Locard, asserts that whenever two objects come into contact, there is an exchange of material that can serve as vital evidence in criminal cases. During forensic investigation, trace evidence is commonly defined at the conceptual level as the surviving evidence of a former occurrence or action of some event or agent; and a very small amount of substance, often too small to be measured. However, at a more practical level, trace evidence is defined as the analysis of materials that, because of their size or texture, transfer from one location to another and persist there for some period of time (Roux et al., 2015). This type of evidence is frequently encountered in incidents involving personal contacts such as homicides, sexual assaults, and hit-and-run cases. Trace evidence can establish connections between objects, individuals, and locations. In cases where DNA or fingerprints are not found, or where they are found but are not in the database system an accumulation of trace evidence can ultimately assist, support, and lead to a successful trial and conviction (Suppajariyawat, 2024).

According to Robertson et al. (2017), fibre is probably the most abundant form of trace evidence found at a scene which can be easily transferred or exchanged between two or more individuals or objects during a simple contact or interaction. They typically come from sources like clothing, furniture, carpets, bedding, and wigs. The most common technique used for fibre analysis is microscopic examination. Different types of microscopes are used to examine the morphology and physical structure of fibres such as colours, shape, and size (Mujumdar and Campiglia, 2018). The identification of fibres is the process of determining the type of fibres based on their composition and morphology structure. According to Houck (2009), The American Association of Textile Chemists and Colorists (AATCC) has lists microscopy as a method to identify fibres but notes that it must be used with caution on manufactured fibres since they are produced in a variety of modifications which alter the appearance. In contrast, American Society for Testing and Materials (ASTM) International favours infrared spectroscopy as the primary method for fibre identification, highlighting the importance of additional physical properties such as density and melting point for confirmation. In forensic science, identifying the fibre may help in establishing links between crime scenes and potential sources. However, forensic scientists often work with limited samples, leading them to rely heavily on microscopy.

This research seeks to investigate the identification and characterisation of various headscarf fabrics as potential sources of trace evidence, thereby enriching the broader field of forensic fibre analysis. The morphology of these fabrics will be examined by analysing their weave patterns and observing how the fibres respond to heat and chemical treatments. The morphological analysis will provide insights into the structural composition of the fabrics, while the reactions of the fibres to heat and chemicals will further elucidate their properties. This comprehensive approach aims to establish a clearer link between fabric characteristics and their significance in forensic investigations.

1.2 Problem Statement

The lack of comprehensive information regarding the fibre morphology and characteristics of common headscarf fabrics in Malaysia poses significant challenges for accurate identification and characterisation in forensic applications. This issue is not only limited to headscarf fabrics; the overall research on textile fibres in Malaysia is notably lacking. Such deficiencies are particularly concerning in the field of forensic science, where precise fibre analysis can provide critical evidence in criminal investigations. Headscarves are widely worn in Malaysia and are typically made from different materials, including cotton, regenerated blends, and synthetic fibres. However, due to the wide variety of fibres used to make textiles, analysis and identification of the fibres is often challenging (Peets et al., 2019). In addition, the current literature fails to adequately document specific morphological features and chemical properties of these fabrics. These 'gaps' are considered as a lack of published identified data in the evaluation of evidence (Ray, 2016). As a result, forensic experts may encounter difficulties in distinguishing between fibres collected at crime scenes and those from everyday clothing, which can lead to misidentifications or the potential overlooking of vital evidence. Furthermore, the complexity of fibre blends can complicate forensic analysis if these materials are not properly characterised. In cases involving headscarves - such as assaults or homicides - the lack of a comprehensive fibre database can significantly impede law enforcement's ability to solve crimes effectively. Therefore, addressing this knowledge gap is crucial for enhancing the reliability and accuracy of forensic fibre analysis in Malaysia.

1.3 Research Questions

i. What are the distinct microscopic characteristics of fibres from different headscarf fabrics commonly used in Malaysia?

ii. Do different types of headscarf fibres react differently to an open flame during the burning test?

iii. How do fibres from different headscarf fabrics react when exposed to various chemical solvents in a solubility test?

1.4 Objectives

1.4.1 Main Objective

To study and identify different types of fibre in different headscarves.

1.4.2 Specific Objectives

1. To examine the microscopic morphology of fibre from different headscarves using a light microscope and stereomicroscope.
2. To analyse the behaviour of fibre through the burning test.
3. To evaluate the solubility of headscarf fibres in various chemical solvents.

1.5 Significance of Study

The identification and characterisation of textile fibres hold considerable significance in forensic science. This relevance stems from the role that fibres play as trace evidence in criminal investigations, where a link can be established between suspects, victims, and crime scenes. The increasing diversity of fabrics used in headscarves, a piece of clothing that is widely used in Malaysia, necessitates advanced techniques and understanding for accurate fibre identification. As mentioned, fibres are classified as trace evidence meaning that they can be transferred from one location to another during a crime. The evidence can link the perpetrator with the crime scene, the perpetrator with the victim, the crime scene with the perpetrator or the crime scene with the victim (De Silva et al., 2021). Hence, forensic experts will utilise the uniqueness of the fibres found at the crime scene to establish the link between individuals and crime scenes. The properties of fibres include their colour, texture, and chemical composition which can provide critical information in investigations.

The uniqueness of fibre evidence is enhanced by the variety of materials used in textiles. For example, headscarves made from polyester or cotton may have distinct properties that can be matched to specific manufacturers or production batches. This specificity increases the evidential value of fibres when found at the crime scene (Peets et al., 2019; Lepot et al., 2023). Different fibres possess unique characteristics that can be identified through careful observation during laboratory testing. By analysing the specific traits of fibres extracted from fabrics, forensic scientists can gain insights into how these materials interact with other possible evidence found at the crime scene. A study conducted by Syed Mohd Daud and Sundram (2019) shows that fabric can retain blood even after being washed and cotton showed the maximum percentage of bloodstain retention.

The results from this study could lay the groundwork for additional research into other types of textiles commonly used in Malaysia, where this could lead to a broader understanding of textile fibres. Other than that, the findings may contribute to developing a comprehensive database of Malaysian textiles that can be utilised by forensic investigators for the identification and comparison of fibres from the crime scene with known sources. By improving our understanding of textile fibres within a Malaysian context, this research aims to improve the investigative methodologies and outcomes in forensic cases involving trace evidence.

CHAPTER 2

LITERATURE REVIEW

2.1 Headscarves and Hijab Definition

Headscarves refer to pieces of fabric worn to cover the head, often for cultural, religious, or fashion purposes. they are widely utilised globally and can be crafted from a wide range of materials, such as cotton, silk, polyester, or blends, tailored to suit different climates and personal preferences. Another term to describe headscarves is known as hijab, an Arabic term that means "barrier" or "cover". In a study made by Hassim (2017), she stated that the act of veiling in its true intention protects a Muslim woman's modesty, both physically and mentally. The translations from the Quran describe cloaking the body to avoid harassment from the opposite sex and displaying religious devotion (Hassim, 2017).

Headscarves are not exclusive to Islam, in recent decades, headscarves have found a prominent place in modern fashion. Global brands and designers have increasingly incorporated modest wear into their collections, creating stylish and functional headscarves that appeal to a wide range of consumers. Fashion blogs and social media influencers have also accelerated this growth alongside e-commerce (Peterson, 2016). In essence, headscarves are more than accessories, profound symbols of faith, culture, and individuality. Hence, the significance of headscarves continues to evolve, including in forensic science, particularly in the realm of fibre evidence.

2.2 Types of Fibre

2.2.1 Natural fibre

According to Nayak et al. (2020), the demand for natural fibres and their textiles instead of synthetic textiles is increasing day by day. Fibres that can be derived or originated from natural renewable resources are called natural fibres (Mondal, 2021). According to the same author, they are bio-based fibres of plant or animal origin, where plant fibres are cellulosic and animal fibres are protein-based fibres. The primary advantage of natural resources lies in their eco-friendliness and biodegradability, as they are derived from natural processes. Unlike synthetic products, which often contain chemicals that can take thousands of years to decompose, natural resources break down more easily and integrate seamlessly back into the environment. Besides these, there is another fibre, asbestos, under mineral fibres which occurs naturally but is not bio-based (Mondal, 2021). It is well-known that the use of asbestos fibres is widely banned in numerous countries around the world due to its detrimental effects on the human body.

2.2.1(a) Animal

Textile fibres are derived from animal sources typically the hairs of mammals, such as sheep's wool which is composed of animal protein keratin (Houck, 2009). Animals produce three main types of hair: vibrissae (whiskers), guard, and fur. Guard hairs are the relatively long, thick hairs which cover the main portion of an animal's body. Guard hairs are the most useful in identifying and comparing animal hairs. Fur hairs, by contrast, are small, thin hairs that provide bulk and warmth: microscopically, they are not very distinctive and may appear similar between otherwise dissimilar animals. Common types include wool, silk and other notable animal fibres include cashmere, mohair, vicuna and angora.

Wool is by far the most important animal fibre used in the manufacture of textile products (Mondal, 2021). Known as "God's gifted fibre" and a "model fibre", it is highly valued for its exceptional textile properties and comfort. Derived from sheep's hair, wool is believed to be the first fibre spun and woven into cloth. Wool fibres have a natural wave or crimp which is a unique characteristic among natural fibres (Robertson et al., 2017). This crimp enables the fibre to interlock and hold together when being spun together into yarn. Fine-quality wool can have up to 12 waves per centimetre, while lower-quality wool may have as few as 2 waves.

Despite its advantages, wool has limitations which it is sensitive to strong alkalis and high temperatures which can compromise its structure. Additionally, During the processing of washable wool, and shrink-resistant wool, the hydrophobic epicuticle is damaged and the scale structure is significantly changed due to the action of chlorine and a cationic resin (Robertson et al., 2017). This occurs because intercellular cement, which binds the cuticle cells and separates them from the cortical cells, is affected during treatment. Wool remains a versatile material used in a variety of clothing and textiles, including sweaters, coats, hats and blankets.

Silk, produced by the *Bombyx mori* silkworm, should not be underestimated in textile production (Houck, 2009). The silkworm, a caterpillar of a small white moth from the insect class *Lepidoptera*, spins silk as a twin filament held together as a single strand by the sericin cement. This sericin acts as a natural adhesive, protecting the fibres during processing and dissolving in hot soap solutions. Raw silk contains approximately 75% fibroin and 25% sericin (Robertson et al., 2017). During wet processing, the de-gumming process removes the sericin, leaving a nearly pure fibroin fibre. Silk fibres can dissolve in potent hydrogen bond-breaking solvents, such as cuprammonium hydroxide.

Renowned as the “Queen of Fibres”, silk exhibits a remarkable array of properties (Mondal, 2021). Its triangular, prism-like structure reflects light at varying angles, giving it a shining appearance. Silk is celebrated for its exceptional strength, durability, softness, and luxurious drape, making it a preferred choice for high-quality apparel. Its application ranges from elegant dress materials and lingerie to handkerchiefs, showcasing its versatility and enduring appeal.

2.2.1(b) Plant/vegetable

Plant fibres are primarily derived from three sources: the seed, the stem, and the leaf, with the choice depending on the most suitable part for a particular plant (Houck, 2009). While the chemical composition of plant fibres varies significantly, their main component is cellulose, responsible for providing strength (Robertson et al., 2017). Other components – lignin and hemicellulose – act as cementing agents within the fibres. Common plant fibres include cotton derived from seeds, flax, jute and hemp derived from a plant's stem.

Among these cotton stands out as the most widely used textile fibre, accounting for nearly half of all processed fibres annually (Houck, 2009). Cotton originates from the seedpods of *Gossypium* plants and is primarily composed of cellulose (91-94%), along with small amounts of water, waxes, fats, proteins, pectins, and mineral salts (Hinchliffe et al., 2016). When the seedpods mature and open, the cotton fibres are exposed to air, drying and collapsing to signal readiness for harvesting. After separation from the seeds, cotton is then compressed into bales, spun into yarn, and twisted to form threads. Finer and thinner threads are more expensive due to their quality.

Cotton has unique properties among cellulosic fibres, including increased strength when wet due to enhanced hydrogen bonding. Maintaining fibre length during harvesting is important, as it ensures strong warping and weaving in fabric production (Delhom et al., 2022). Additionally, its porous structure allows airflow, making it breathable and ideal for a variety of applications, cotton is used to produce socks, shirts, pants, skirts, bed sheets, curtains, and medical items such as bandages and wound dressing.

2.2.2 Man-made fibre

Man-made fires are fibres that are created or manufactured by humans through chemical, mechanical, or industrial processes rather than being naturally obtained in their usable form. They are engineered to meet specific requirements or to mimic the properties of natural fibres. The chief benefits of utilizing man-made fibres are having tensile strength and good resistance against acid and alkali and the cost is less due to abundance in availability (Basu et al., 2023). Several studies on fibres have concluded that, although instances of low modulus have occasionally been observed, significant improvements can be achieved in terms of strain capacity, toughness, impact resistance, and crack control. Man-made fibres can be classified into two main categories: synthetic fibre and regenerated fibre.

2.2.2(a) Synthetic fibre

Synthetic fibres are a category of man-made fibre entirely crafted from chemical substances, predominantly derived from petroleum-based products, which is why they are referred to as fully artificial fibres. These fibres are composed of long chains of hydrocarbons formed through chemical reactions (Hinchliffe et al., 2016). The production involves polymerization, where monomers – smaller molecular units – are chemically bonded to create a long chain of polymers that serve as the structural backbone of synthetic fibres. Some common examples of synthetic fibres include nylon, polyester, acrylic, spandex (lycra), and polypropene. Each of these fibres is engineered to possess specific characteristics that make them highly versatile for various applications.

2.2.2(a)(i) Nylon

Nylon is a manufactured fibre formed from a long-chain synthetic polyamide in which at least 85% of the amide linkages are attached directly to two aromatic rings (Cotton Incorporated, 2013). The most common types are nylon-6 and nylon-6,6, which are known for their strength, elasticity and versatility. Lightweight and highly elastic, nylon is widely used in apparel such as tight, stocking, and sportswear, where its stretchability and durability enhance comfort and fit. Its low moisture absorbency makes it quick-drying, an ideal property for activewear and outdoor gear like hiking clothes and raincoats. Furthermore, nylon is elastic and light making it suitable for winter clothing (Liwei Textile, 2022). Nylon's abrasion resistance and high-temperature tolerance make it suitable for industrial applications including ropes, fishing nets, and automotive components.

Despite its advantages, nylon has environmental drawbacks due to its petroleum-based production and non-biodegradability. However, recycled nylon fibre (RNF) derived from nylon waste can be used in fibre-reinforced concrete (FRC) as an eco-friendly and cheaper alternative to engineered fibres. (Farooq et al., 2022).

2.2.2.(a)(ii) Polyester

Polyester fibre, the most common being polyethene terephthalate (PET), dominates the global synthetic fibre industry (Robertson et al., 2017). By 2004, polyester accounted for 77% of global synthetic fibre production, with an anticipated growth rate of 7% over the next decade. Polyester is an exceptionally versatile fibre with a broad range of applications including carpets, industrial fibres, yarns for tyre cords, car seat belts, sailcloth, and various fabrics for apparel and household furnishing. Chemically, polyester is formed from any long-chain synthetic polymer consisting of at least 85% the ester of a substituted aromatic carboxylic acid (Cotton Incorporated, 2013). All polyesters are chemically inert, offering a variety of performance features, but limited modifiability. Being oleophilic, they strongly attract oils and therefore must be treated with a soil-release chemistry to prevent soiling and body-odour retention.

Polyester fibres are melt-spun to create filament yarns and staple fibre, the length of staple fibres varies based on the spinning system, while filament yarns are often textured to increase bulk. Staple fibre may also be crimped to enhance bulkiness and improve compatibility with wool spinning. To adjust the fibre's lustre, titanium oxide is added, with varying quantities used to produce dull or bright yarns. Polyester and polyester blended fabrics can be heat set to give dimensional stability and prevent shrinking during domestic laundering (Robertson et al., 2017). Additionally, polyester fabrics demonstrate superior resistance towards ultraviolet light compared to comparable nylon products, making them highly durable and easy to maintain.

2.2.2.(a)(iii) Lycra

Lycra, also known as Spandex or Elastane in some regions, is a highly elastic synthetic fibre known for its exceptional stretchability, comfort and versatility. According to Cotton Incorporated (2013), they have extremely high elongation, at least 200% and in some cases up to 800%. However, the fibre is much more costly than other fibres, hence garments made of 100% lycra are not very popular. Instead, a certain percentage (5% to 10%) of lycra is used with other fibres to make stretchable fabric/garment (Ray, 2011). Lycra modernised traditional fabrics, when combined with natural fibres, enabling the creation of clothing, swimwear, underwear, hosiery, compressed surgical garments and interior furnishings that were elastic, functional, and comfortable to wear (Sinclair, 2014).

2.2.3 Regenerated fibre

Regenerated fibres are a category of man-made fibres produced by chemically processing natural raw materials, primarily cellulose, which is the most abundant organic compound found on earth (Ribul, 2021). The key features of regenerated fibres lie in their production process, where natural materials like wood pulp, or cotton liners are dissolved in specific chemical solvents to create a polymer solution, this solution is then regenerated into solid fibre forms using various spinning techniques, such as wet spinning or dry spinning (Kim et al., 2022). As a result, regenerated fibres are a blend of natural and artificial components, as they are derived from natural sources but undergo chemical transformation, making them distinct from both fully synthetic and purely natural fibres.

Regenerated fibres have similar characteristics to natural fibre. It is soft, and loose and has good absorbance properties, making them comfortable and suitable for a range of textile applications (Thomas et al., 2011). These fibres can be engineered to mimic natural fibres like cotton or silk while maintaining consistent quality and performance. It is also considered more sustainable compared to synthetic fibres as they are produced through eco-friendly methods. Common types of regenerated fibres include viscose (rayon), modal, lyocell, acetate and moss crepe.

2.2.3(a) Viscose rayon

Rayon is the generic term used for fibre, and the resulting yarn and fabric manufactured of regenerated cellulose (Shaikh et al., 2012). The development of viscose rayon began with the concept of "artificial silk" theorized by Robert Hooke in 1664. However, it was not until 1855 that Frenchman George Audemars successfully created a thread by dipping a needle into a viscous solution of mulberry bark pulp and gummy rubber, although this method was inefficient and impractical for large-scale production. The breakthrough came in 1892 when English chemists Charles Frederik Cross, John Bevan, and Clayton Beadle discovered the viscose process (Shaikh et al., 2012). The fibre then was officially named "rayon" in 1924 by the U.S. Department of Commerce committee, inspired by its brightness and resemblance to cotton. The term "viscose" comes from the word "viscous", describing the sticky spinning solution used in its production.

Viscose fibres are created using natural cellulose as the raw material, such as cotton and wood pulps, and are processed using either derived cellulose or direct dissolution (Xu et al., 2023). The manufacturing process involves several chemical treatments: cellulose is first steeped in sodium hydroxide and shredded into alkali cellulose, aged, and then treated with carbon disulphide to form cellulose xanthate. This compound is then dissolved in dilute caustic soda to create viscose, which is spun into filaments through an acid bath, regenerating it into cellulose. The filaments are then stretched, washed, and dried to produce versatile fibres tailored for various uses. Viscose rayon is the most absorbent of all cellulose fibres, even more so than cotton and linen (Shaikh et al., 2012). Thus, making it an excellent summer fabric. Other products include blankets, tablecloths, sportswear, medical surgery products and many more.

2.2.3(b) Moss crepe

Moss crepe is a fabric made from regenerated fibre, known for its unique crinkled texture, soft drape, and versatility. Moss crepe fabric can be crafted using various methods, with its defining feature being its distinctive textured wave. These unique characteristics have inspired many designers and textile manufacturers to experiment with multiple techniques to achieve the signature "crepe" effect. Crepe originates from the French word crinkle, formed by firmly twisting fibres substantially tighter than average, achieved by alternating "S" as well as "Z" twist (Hasan, 2022). The S-twist is also known as the left-hand twist and the Z-twist is known as the right-hand twist. Moss crepe can be used to make dresses, skirts and suits (Amenya, 2022). While it is relatively easy to maintain thanks to its wrinkle-resistant nature, it requires gentle washing to preserve its texture and may lose strength when wet. Despite these limitations, its eco-friendliness, derived from its cellulose base, makes it sustainable making it a high-demand product in the fashion and textile industry.

2.3 Fabric Construction Method

2.3.1 Woven fabric

Weaving is one of the oldest and most versatile fabric construction methods. Every piece of woven fabric is an integration of warp yarns (longitudinal, or lengthwise) and weft yarns (transverse, or width wise) through the intersection (Jilian, 2018). Woven fabrics are produced on looms, where the selvedge (edge of the fabric) can give valuable information, if present, as to the type of the loom on which the fabric was woven (Robertson et al., 2017). The warp fibres are arranged parallel to the fabric's edge, while the weft fibres are inserted into the fabric using various methods. These methods include: projectile weaving, where the weft is transported across the loom by a projectile, with the yarn being cut and a small end tucked back; rapier weaving, where two rapiers carry the weft across the loom, passing the yarn from one to the other, leaving a fringe at the selvedge when the yarn is cut; air jet weaving, where the weft is propelled by a series of air jets, creating a fringe at the selvedge; and waterjet weaving, commonly used for weaving lightweight 100% polyester fabric, where the weft is carried by a jet of water, also leaving a fringe at the selvedge. Several basic woven fabric structures include plain weave, twill weave, satin weave, sateen weave, jacquard weave and tufting.

2.3.1(a) Plain weave

Plain weave is the simplest of all the woven structures and the most economical to produce (Robertson et al., 2017). The weave is formed by the yarns at a right angle passing alternatively over and under each other. Weft yarns interlace with the warp yarns to form the maximum number of interlacing. Because the warp and weft yarns are equally visible on both sides, plain weave fabrics have a uniform appearance and are typically reversible. Variations in the plain weave can be achieved by altering the thickness (count) or spacing of the yarns. If the warp and weft yarns are the same count and the same distance apart then the weave is considered to be balanced. Conversely, if there are twice as many yarns in one direction than the other, an unbalanced rib plain weave is formed. In such cases, the thicker weft yarns create a prominent ribbed texture, which increases abrasion resistance. However, plain weave design also shows lower strength and elongation compared to twill and satin weave (Begum and Milašius, 2022). A variation on the plain weave structure is the basket weave where two or more adjacent warp interlace with the weft yarns and the yarns follow the same parallel path (Robertson et al., 2017).

Plain weave fabrics have no technical face or back, as both sides appear identical. However, when printed, the face and the back can be distinguished by the design (Figure 2.1). The flat surfaces of plain weave fabrics make them ideal for printed patterns, enhancing their decorative potential. However, because of a large number of interlacing plain woven fabrics made from natural fibres have the tendency to wrinkle (Robertson et al., 2017). Common examples of plain weave include muslin, a lightweight, breathable fabric often used for clothing and curtains; canvas, and calico.

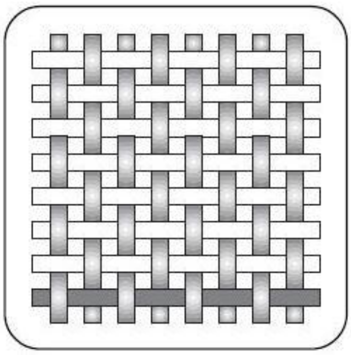

Figure 2.1 Plain weave (Source: https://www.colan.com.au/compositereinforcement/resources/manufacturing/weave-information/plain-weave/)

2.3.1(b) Twill weave

Twill weave is a more complex weaving pattern characterized by its diagonal lines or ridges, known as wales, which are formed by the weft yarn passing over two or more warp yarn before going under one, resulting in a diagonal in the warp direction of the fabric (Figure 2.2). It can appear as either right-hand, left-hand twill or combination. Twill weaves such as denim are very common, due to their high fibre density and excellent wear resistance making the twill construction very suitable for industrial clothing and workwear (Robertson et al., 2017).

Herringbone is a distinctive variation of the twill weave, characterized by the reversal of the twill direction at regular intervals, creating a zigzag or chevron-like. This unique structure enhances the visual appeal of the fabric while retaining the strength and durability inherent to twill weaves. Both herringbone and traditional twill fabrics are commonly used in upholstery due to their robust construction and ability to camouflage stains, making them ideal for high-traffic or frequently used surfaces.

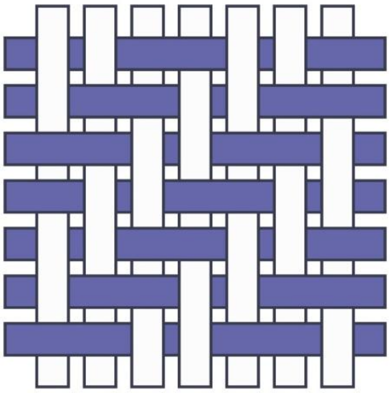

Figure 2.2 Twill weave

(Source: https://www.vectorstock.com/royalty-free-vector/fabric-2-by-twill-weave-type-sample-vector-40901545)

2.3.1(c) Satin weave

The satin weave is a luxurious weaving pattern that creates a fabric with a smooth, glossy surface and a dull back. It is the last of the basic weaves, considering their relation to simple and compound textiles. The name is ordinarily understood to mean a silk fabric woven in a certain way; it should however refer to the weave and not the material, and it will be used in that sense only in this classification (Reath, 1927). The lustrous of the satin weave is due to the long warp floats on the fabric surface which referred to as warp faced. According to Robertson et al. (2017), the warp yarns floats over four to eight weft yarns before it passes under one weft yarn, which will result in a fabric with a smooth surface. The back of the fabric resembles twill particularly if coarse yarns are used. The combination of fine yarns and long floats contribute to the satin weave's luxurious texture but also makes it prone to certain drawbacks, such as low abrasion resistance and a tendency to sag. The combination of fine yarns together with the long floats on the surface result in a fabric with low abrasion resistance but is prone to sagging. Besides that, satin and sateen weaves are always misunderstood as having the same pattern. sateen weave is a derivative of satin weave (Whewell and Abrahart, 2019), with the primary difference being the yarn orientation. Satin weave is warp-faced, meaning the warp yarns dominate (float) the surface, while the sateen weave is weft-faced, with the weft yarns floating on the surface (Figure 2.3). The long floats in satin weave contribute to its aesthetic appeal, which is highly sought for special occasions such as bridal gown and evening wear, as well as in home textiles includes satin sheets, and decorative pillowcase.

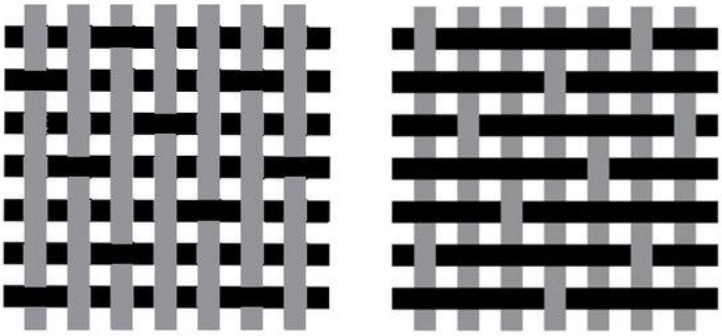

Figure 2.3 Satin weave (left) and sateen weave (right)

(Source: https://linensnow.com/blogs/all-about-home-textiles/satin-sateen-and-silk)

2.3.2 Knitted fabric

Knitting is another major fabric construction method. In knitting, loops of yarn are interlocked using needles to create fabric. Unlike weaving, which interlaces yarns at a right angle, knitting uses a series of loops to form the fabric. There are many advantages to knitted fabrics compared to woven fabrics, these include the ability of the knitted garment to adapt to body shape due to the elasticity of the knitted loop woven (Robertson et al., 2017). Knitted fabrics are ideal for active individuals due to their superior comfort and ability to maintain their appearance over time. However, a drawback of their loop structure is a tendency to sag with extended wear or snag when coming into contact with sharp objects. There are two primary types of knitting: weft knitting and warp knitting. While both forms of knitting consist of loops, there are significant differences in the performance and the structure of the fabrics produced (Robertson et al., 2017).

2.3.2(a) Weft knit

In weft knitting, the yarn is fed across the width of the fabric, and each row of loops is formed one at a time, the loops are interlocked with one another, resulting in a fabric that is stretchable and flexible. Weft knitting can therefore be divided into flatbed knitting where the yarns move back and forth and circular knitting where the needles are arranged around a cylinder, and the yarns move horizontally (Robertson et al., 2017). In weft knitting, each row of loops builds on the previous row, resulting in a fabric that is highly stretchable in both lengthwise and width wise directions. This is ideal for garments that need to move with the body.

There are several types of weft knitting, each producing fabrics with unique properties. Single jersey knit, for instance, is the simplest form, creating a fabric with a smooth surface on one side and a slightly textured surface on the other. This type is widely used for T-shirts and lightweight apparel. Rib knits fabrics are the next most popular to single jersey knit fabrics where the simplest knit is 1x1 rib and is made of face wales and back wales, forming lengthwise ridges on both sides of the fabric by pulling adjacent stitches first to the face and next to the back of the fabric (Robertson et al., 2017). Another variation, interlock knit, is a double-sided fabric that is thicker, more stable, and smoother on both sides, often used in activewear and underwear. As for more intricate designs, jacquard knit uses multiple yarns to create patterns directly within the fabric, commonly found in high-end garments and decorative textiles.

2.3.2(b) Warp knit

In warp knitting, the yarn runs lengthwise, and multiple needles work simultaneously to form the fabric, producing a more stable structure with less stretch compared to weft knitting. This method creates a more stable and less elastic fabric structure, making it suitable for applications requiring strength and durability. Warp knitting is typically performed on specialised machines, as the process is more complex than weft knitting. Examples of warp knit are tricot knit and raschel knit. Tricot knit is produced using fine yarns, resulting in lightweight, smooth fabric with a soft texture and commonly used in lingerie, swimwear and sportswear. Raschel knit is characterised by its open, lace-like structure, often used in lace, nets and decorative textiles. Warp knitted fabrics have a wide variety of applications these include home furnishings, lingerie, medical products and technical fabrics (Robertson et al., 2017). Warp knitted offers significant advantages such as resistance to sagging and greater durability, unlike weft knitted fabrics. however, these fabrics have limited stretch compared to weft knits.

2.4 Methods for Identification

2.4.1 Morphological test

A morphological test describes the physical appearance of the fabric and fibre. Morphological testing for fibre examination and identification is an important aspect of textile analysis, enabling the differentiation of various fibre types based on their structural characteristics. This process typically involves several techniques, with microscopy being one of the most reliable methods for assessing the unique morphological features of fibres. In addition, positive identification of many natural fibres is possible using the microscope (Truents, 2010). This test is done by observing the general appearance of the fabric, the structure and the texture of the fibre. According to (Mukhopadhyay, 2013), the colour of natural fibre is usually white and has irregular characteristics. Cotton fibres often show a ribbon-like twisted structure with a distinct lumen (James et al, 1999), wool fibres exhibit overlapping scales and crimped appearance, while silk usually appears smooth with a triangular cross-section. As for the weaving pattern, the most common weave is plain weave which is often encountered in cotton fabrics.

Synthetic fibres on the other hand, have uniform and structures due to their man-made production process. Under a microscope, they may appear smooth, and cylindrical, often have a circular or trilobal cross-section. The uniformity of synthetic fibres makes them distinguishable from natural fibres, hence helps in the identification of fibre which can provide valuable forensic evidence.

2.4.2 Burning test

The burning test is a straightforward and effective method for examining and identifying fibres by observing their behaviour when being exposed to a flame. This test is particularly useful for differentiating between natural and synthetic fibre. Burning behaviour comprises behaviour of the fibre when approaching flame, in flame, removed from flame, its odour and residue (Sekhri, 2022).

In general, fibre made from cellulose will exhibit similar burning behaviour. They ignite easily, emit an odour similar to the burning paper, and leave behind a fine, grey ash residue. Additionally, cellulosic fibres tend to display an afterglow once removed from the flame, in contrast, protein-based fibre such as wool and silk, do not burn readily. They are self-extinguishing, emitting a characteristic odour of burning hair or feathers. The residue from protein fibres forms a brittle bead that can be easily crushed. Synthetics behave differently, often curl away from flame and melt (Sekhri, 2022). These fibres emit a distinct chemical odour when exposed to heat, and leave behind a hard, sold bead as residue

2.4.3 Solubility test

A solubility or chemical test has been used for the confirmation method. This test is often conducted alongside other techniques, such as morphological test and spectroscopic methods, to provide a comprehensive profile of the fibre. Different reagents react with specific compounds present in the fibres and hence the confirmation can infer (Sekhri, 2022). Synthetic fibres, sometimes there is some confusion during the burning test, and since fibres are polymeric materials, they can react with solvents in different ways (Fan, 2005). Thermoplastic fibres can dissolve in common solvents such as acetone, although highly semi-crystalline thermoplastic fibres like nylon and polyester require more harsh solvents, such as formic acid or boiling dimethylformamide (DMF). In these cases, the fibre polymer undergoes chemical breakdown and will be dissolved. Natural fibres like the cellulosic and protein fibres are thermosetting polymers, and found to be dissolved chemically in strong acid or base solution (Fan, 2005). This distinct solubility behaviour is important aspect for identifying, quantifying and conforming the composition of blended fibre fabrics, such as polyester/cotton or nylon/wool. By examining the solubility of different fibres in a range of different solvents, one can determine the proportions and types of fibre present.