CHAPTER 3

MATERIALS AND METHODS

3.1 INTRODUCTION

It is evident from the literature review that the comfort characteristics of fabrics mainly depend on the structure, types of raw materials used, its weight, moisture absorption, heat transmission and skin perception characteristics of the fabrics. Developing functional Hospital textiles was carried out in the following steps:

- Study of the functional requirement of the medical textile products and understanding the characteristics of the existing products.
- Selection of suitable fiber content, yarn and fabric construction techniques and finishing treatments from the comfort point of view.
- Design and development of single layered and multilayered hospital textiles along with pressure relieving mattresses.
- Analyses of the functional properties of the developed products.

3.2 MATERIALS

This research work aims at developing fabrics with enhanced comfort and functional properties by combining fibers in different proportions and weaving fabrics with specific structures to improve surface characteristics. Single and multilayered bed linens along with a mattress are engineered and designed to reduce pressure, temperature, shear and friction
developed on the body and also to enhance the thermal, moisture and moisture vapour transport properties of the bed sheets. Single and multilayered bed linens were designed using the fibers like lyocell, micro lyocell, micro polyester, bamboo, bamboo charcoal and their blends with polyester.

3.2.1 Fiber Selection

The prime fiber component of this research is lyocell, a regenerated cellulosic fiber, which has good breathability, moisture absorption, smooth fiber surface, low wet cling tendency, maintaining dry and cool micro climate on the skin which are a few essential properties of medical textile products. Due to the combination of smooth fiber surface and excellent moisture absorption, lyocell creates a chemical-free, positive environment for healthy skin, making it ideal for anyone with sensitive skin. According to recent dermatological studies, it was found that wearing clothing made of lyocell significantly improves comfort and promotes a feeling of well-being. Hence, lyocell is selected as the base fiber and effort is made to enhance its comfort and mechanical properties by blending it with other fibers.

It is also ascertained from literature that even though polyester is a hydrophobic fiber, blending small proportion of polyester with hydrophilic fiber enhances the wickability and drying characteristics of the resultant fabrics. Hence polyester fiber was selected to blend with lyocell fiber in different blend ratios to produce yarns with improved comfort characteristics.

Micro denier fibers of lyocell and polyester are selected for developing bed linens, because these fibers have some special and unique properties which fulfil the research objectives. The microfiber fabrics have higher fiber and fabric surface area, which helps in transporting water and water vapour out of the skin by their superior capillary action. The higher
pore density also provides better thermoregulation. Hence these two fibers are selected to produce blended yarns with varying blend proportions from which hospital textile products were developed.

Bamboo fiber is opted for this research work because of its distinctive properties which makes it suitable for medical textile applications. Since bamboo fabric has an unusual level of breathability, making it incredibly cool and comfortable to wear with an added advantage of inherent anti-microbial resistance, bamboo fiber is selected to develop hospital textile products.

Bamboo charcoal fiber is selected as the next suitable fiber for this research work because of its special characteristics which makes it ideal for medical textile applications. Possessing extraordinary microstructure, bamboo charcoal absorbs odor and humidity from the indoor air, emits natural smell, and radiates far infrared energy as well. The activated carbon in bamboo charcoal is efficient in adsorbing odorous volatile micro-organisms thereby reducing the odor and growth of micro-organisms; hence it is used in hospital textiles for reduction of microbial growth and adsorption of wound odor.

3.3 METHODS FOR DEVELOPMENT OF HOSPITAL TEXTILES

Single and multilayered fabrics needed for the development of hospital textiles were produced using the following fiber combinations.

- Lyocell and its blends with polyester
- Micro lyocell and its blends with micro polyester
- Lyocell yarns with bamboo and bamboo/cotton yarns
- Lyocell yarns with bamboo charcoal yarns
3.3.1 Experimental Design

The overall work plan of the research work is given in the flow chart below.

![Process Flowchart for Experimental plan](image-url)

Figure 3.1 Process Flowchart for Experimental plan
3.3.2 Yarn Production

The major fiber component lyocell is blended with polyester in different blend proportions to produce 30s ring spun yarns. Since blending a small proportion of polyester with lyocell enhances the wickability and drying characteristics of the resultant fabric without compromising the comfort properties of lyocell, only minor component of polyester is blended with lyocell. The following blend ratios are selected for producing blended yarns.

- 100% Lyocell
- 85:15 Lyocell/Polyester
- 70:30 Lyocell/Polyester

Similarly, Micro polyester and Micro lyocell fibers were blended in the following blend ratios to investigate on the comfort properties of the blended fabrics.

- 100% Micro Lyocell
- 85:15 Micro Lyocell/Micro Polyester
- 70:30 Micro Lyocell/Micro Polyester
- 100% Micro Polyester

The fiber parameters of the selected fibers are given in the Table 3.1.

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Denier</th>
<th>Fiber length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyocell</td>
<td>1.2</td>
<td>38 mm</td>
</tr>
<tr>
<td>Polyester</td>
<td>1.2</td>
<td>38 mm</td>
</tr>
<tr>
<td>Micro Polyester</td>
<td>0.8</td>
<td>38 mm</td>
</tr>
<tr>
<td>Micro lyocell</td>
<td>0.9</td>
<td>38 mm</td>
</tr>
</tbody>
</table>
Blending of fibers and yarn production was carried out using advanced, micro processor based spinning plant containing computer controlled carding, draw frame, simplex and ring frames.

3.3.3 Production of Woven Fabrics

Fabric samples were prepared in a sample loom attached with dobbay and drop box facilities running at a speed of 56 picks per min. It is a power operated shuttle loom with a loom width of 36”.

3.3.3.1 Selection of Fabric Cover Factor

Since the comfort and surface properties of fabrics like air permeability, water vapour permeability thermal conductivity and frictional coefficient depend on the fabric cover factor, a suitable cover factor, which maximizes all comfort properties, was determined by analyzing fabrics with four different cover factors. As lyocell is the major component of all the fabrics developed, fabric samples were produced from lyocell yarn with four different cover factors such as 20, 22, 24 and 26 by varying the ends per inch and picks per inch and analyzed for their comfort properties to select the suitable cover factor.

3.3.3.2 Development of Blended Yarn Fabrics

Since the objective of the research is to ensure appropriate heat transfer, moisture management and air transport between the human body and the environment, and the type of weave structure affects the water absorption and frictional characteristics of a fabric, three types of weaves were considered for fabric production. Based on the literature survey, it was decided to produce fabrics with plain weave, 2/2 twill weave and 1/3 twill weave.
From each of the blended yarns produced, three different fabrics with plain weave, 2/2 twill weave and 1/3 twill weave were produced with the selected cover factor. Hence nine different fabric samples were produced with 100% lyocell, and 85:15, 70:30 lyocell/polyester blended yarns and similarly, twelve fabric samples were produced from micro lyocell and micro polyester blended yarns.

3.3.3.3 Development of Union Fabrics

Union fabrics are produced by incorporating lyocell yarn in different proportions with other categories of yarns like Bamboo, Bamboo Cotton, and Bamboo charcoal. For example union fabrics from bamboo charcoal and lyocell yarns were produced by selecting the warp and weft yarn proportion the following ways:

- 100% bamboo charcoal fabric is produced by weaving the bamboo charcoal yarn in both warp as well as weft directions.
- 75% bamboo charcoal and 25% lyocell blended union fabric is produced by using bamboo charcoal yarn in warp direction and both lyocell combined with bamboo charcoal yarn in weft direction.
- 50% bamboo charcoal and 50% lyocell blended union fabric is produced by using bamboo charcoal yarn in warp and lyocell yarn in weft direction.
- 25% bamboo charcoal 75% lyocell blended union fabric is produced by using bamboo charcoal yarn and lyocell yarn in warp and lyocell yarn alone in weft direction.

From each proportion, three types of woven structures were produced with plain weave, 2/2 twill weave and 1/3 twill weave. Thus 12
fabric samples were woven from each fiber combinations. Similarly, 12 fabric samples from bamboo/lyocell combination, 12 fabric samples from bamboo cotton/lyocell were produced.

All the fabric samples are tested for various properties like water vapour permeability, air permeability, fabric strength and elongation, fabric linear density, thickness, vertical wicking, in-plane wicking, absorption rate, spreading area, frictional coefficient, thermal conductivity and anti-microbial activity.

3.3.3.4 Development of Multi Layered Knitted Fabrics

Double-faced fabric also called as tri-layer fabric, was produced from weft knitting machines with two sets of needles, which has the ability to create two individual layers of fabric that are held together by tucks. Double-face fabrics are produced on dial and cylinder circular knitting machine and it requires the use of, at least, three different yarns for each course of visual fabric. The degree of space or height between the two fabric faces is determined in the circular knitting machine by the setting of the dial height relative to the machine cylinder. Tri-layer heights preset in this way can vary between 1.5 and 5.5 mm.

Production of knitted tri-layer fabrics on dial and cylinder machines was done using a variety of combinations of stitches that ultimately connect two independent layers of fabrics together. This technique requires the use of, at least, three different yarns for each course of visual fabric: 1) yarn for the cylinder needles; 2) yarn for the dial needle; 3) a tri-layer yarn, normally monofilament yarn connecting the two layers. In the following notation, long lines represent high butt needles and short lines represent low butt needles. Interlock needle gaiting is shown. The basic steps involved in the production of tri-layer fabric is as follows,
Figure 3.2 Tri-layer Knitted Structure

a) Tucking on dial and cylinder needles at the same feeder.

b) Tucking on the dial and cylinder needles on feeders 1 and 4 on low and high butt needles alternately (this connects the two layers together);

c) Knitting dial needles with dial yarn at feeders 2 and 5 on low and high butt needles alternately;

d) Knitting cylinder needles with cylinder yarn at feeders 3 and 6 on low and high butt needles alternately;

Two types of tri-layer fabrics were produced using the following fiber combinations:

- Bamboo charcoal/Micro polyester/Lyocell
- Bamboo /Micro polyester/Lyocell

3.3.3.5 Development of Multi Layered Woven Fabrics

The tri-layer woven fabric was produced in a sample loom using three warp sheets and two weft yarns. In bamboo charcoal/lyocell/micro polyester combination fabrics, the top layer contains bamboo charcoal yarn in
warp direction and lyocell in the weft direction. Lyocell is introduced in the weft direction to ensure maximum moisture spreading along the width of the fabric, so that the wetness is transferred away from the body of the patient. In the bottom layer, lyocell is used as warp and micro polyester as the weft to ensure rapid transfer of water from the inner layer and faster drying. The connecting layer is made of micro polyester warp which interweaves with the face and back weft alternatively, assisting in moisture transfer from the inner layer to the outer layers. Micro polyester with high wicking ability acts as an efficient medium to transfer moisture from the inner layer to the outer layer.

In the bamboo, lyocell micro polyester combination fabric, bamboo yarn is used in the top layer in both warp and weft directions. In the bottom layer, lyocell yarn is used in the warp direction and micro polyester in the weft direction. The connecting layer is made of micro polyester warp which interweaves with the face and back weft alternatively.

3.4 TESTING METHODS

The various test methods used to test the yarn and fabric samples are given below.

3.4.1 Testing of Yarn Properties:

Linear density of yarn was calculated as per ASTM D 1059-2001. The tensile properties such as breaking tenacity and elongation of yarn samples were tested using Tensomaxx 7000 single yarn strength tester as per ASTM D2256 standard test method using 200 samples. Twist per inch for the yarn samples were determined as per ASTM D-1422, standard test method using STATEX Twist tester with ten yarn samples.
3.4.2 Testing of Fabric Parameters

Ends per centimeter and picks per centimeter of the fabrics were measured as per ASTM D 3775-96 using counting glass. Thickness of the fabric was calculated as per ASTM D 1777-07 at 10 different places for each specimen and an average was taken for further analysis. Arial density of fabric was calculated as per ASTM D-3776 -96, using a standard cutter and the mean value of five samples was reported.

3.4.2.1 Measurement of Fabric Strength and Elongation

Fabric strength and elongation is found by using Tensomaxx 7000 instruments by ASTM D5034 test method. The grab test is a tensile test where the central part of the specimen's width is tested in the grips. The specimen of size 100 mm x 150 mm long is pulled to break at 300 mm/min (12 in/min) and the breaking strength and elongation were measured using ten fabric samples.

3.4.3 Measurement of Air Permeability

The air permeability of the fabric was measured in cm$^3$/cm$^2$/s using air permeometer at an air pressure of 100 Pa as per the ASTM D 737 standard testing procedure and twenty samples were tested for each fabric.

3.4.4 Measurement of Wickability

In this method, wick up was observed by determining height to which water moves upward on a strip of 12.5cmx2.5cm suspended vertically with its lower ends dipping into a dye solution (50g dye in 100ml of water) as per BS3424. The effect was observed for both warp and weft directions for a specified time and twenty fabric samples were tested in each way. Higher wicking value shows greater liquid water transport.
3.4.5 Measurement of Drying Rate

Quick drying capability of the fabric was evaluated by its drying rate as per ASTM D 4935-99. The specimen of the size 100x100 mm$^2$ was put on the plate of the balance and the dry weight was recorded as $w_f$ (g). The weight of water previously added in fabric was equal to 30% of the dry weight and then the wet weight was recorded as $w_o$ (g). The change in weight of water $w_i$ (g) at regular intervals was continuously measured for twenty fabric samples. The remained water ratio (RWR) was calculated using the following equation (3.1) to express the change in water weight remained in the specimen over the time for drawing the evaporating curve from 100% to 0%:

$$\text{RWR} \, (\%) = \left[ \frac{w_i \, (g) - w_f \, (g)}{w_o \, (g) - w_f \, (g)} \right] \times 100\% \quad (3.1)$$

3.4.6 Measurement of Thermal Conductivity

Thermal conductivity (K) is an intensive property of the material that indicates its ability to conduct heat. It is defined as the quantity of heat $Q$, transmitted through a thickness $L$, in a direction normal to a surface of area $A$; due to temperature difference $\Delta T$, under steady state conditions and when heat transfer is dependent only on the temperature gradient,

$$\text{Thermal Conductivity} = \frac{\text{heat flow rate} \times \text{distance}}{(\text{area} \times \text{temperature difference})}$$

$$K = \frac{Q \times L}{(A \times \Delta T)} \quad (3.2)$$

Determination of thermal conductivity for all the fabric samples was carried out using Lee’s Disc method with a sample size of twenty.
3.4.7 Inplane wicking Test

Inplane wicking or transverse wicking is the transmission of water through the thickness of a fabric that is perpendicular to the plane of the fabric. It is perhaps of more importance than longitudinal wicking because the mechanism of removal of liquid perspiration from the skin involves its movement through the fabric thickness. Transverse wicking is more difficult to measure than longitudinal wicking as the distances involved are very small and hence the time taken to traverse the thickness of the fabric is short. Determination of inplane wicking was carried out using the plate test which consists of a horizontal sintered glass plate kept moist by a water supply whose height can be adjusted so as to keep the water level precisely at the upper surface of the plate. Rate of water absorption in transverse direction is determined by measuring the mass of water taken up by the fabric in a given time. Twenty fabric samples were tested for each category of fabrics developed.

3.4.8 Measurement of Water Vapour Permeability

The rate of moisture vapour diffusion through the fabric is determined according to the simple dish method, similar to ASTM E96-80. In the British standard version of this method, the specimen under test is sealed over the open mouth of a dish containing water and placed in the standard testing atmosphere. After a period of time to establish equilibrium, successive weighings of the dish are made and the rate of water vapour transfer through the specimen is calculated. Then the rate of moisture vapour loss (MVTR) is calculated in units $\text{g/m}^2 \cdot 24 \text{ hours}$ for twenty fabric samples. Higher MVTR value indicates there is a greater passage of moisture vapour through the material.
3.4.9 Measurement of Water Absorption Rate and Spreading Area

The ability of the fabric to absorb water is measured by spreading action as per AATCC 79:2000. A sample of size 20cm x 20 cm was taken and a drop of water was allowed to fall on the flat fabric surface. Area has been kept constant for finding out water spreading in seconds. The height of water drop is controlled by a syringe, which contains one ml of water. The time taken to completely absorb one drop of water measured in seconds is the absorption rate. Once the droplet gets completely absorbed, the spreading area is measured in cm$^2$ for twenty fabric samples. The spreading of water on any material increases when the resistance to water flow is low.

3.4.10 Measurement of Fabric Frictional Factor

Fabric frictional coefficient was measured as per ASTM D1894 standard using a computer aided friction tester, designed and developed exclusively for characterizing friction in fibers, sheets of yarn, fabrics, nonwovens, polymeric films, composites and other technical textiles. Fabric friction is determined by measuring the force that opposes relative motion between two fabric surfaces in contact.

The instrument with the aid of online computer and application software, measures fabric-to-fabric friction and determines various frictional parameters, like the Static Frictional Force which is the maximum force required to cause sliding between the two fabric assemblies; the Dynamic Frictional Force, which is the average force required to cause continued sliding between two fabrics, and also records the friction profile.

Rectangular fabric samples of 5 cm x 2.5 cm were prepared and unraveled at edges to correct the grain in the warp and weft direction. The fabric samples are clamped in such a way that the fabric samples lies one
over the other with the normal load of 100g placed above them. The clamp
starts to move at a speed of 100 mm/min with a total displacement of 12mm.
The static and dynamic frictional factors were recorded using a computer
integrated with the testing instrument for ten samples in each category of
fabric.

3.4.11 Measurement of Microbial Resistance

Microbial resistance was measured using AATCC 100, Quantitative Test method in which specimens of the test material were shaken in a known concentration of bacterial suspension and the reduction in bacterial activity in standard time was measured. The efficiency of the antimicrobial treatment was determined by comparing the reduction in bacterial concentration of the treated sample with that of the control sample expressed as a percentage reduction in standard time. The bacterial counts were reported as the number of bacteria per sample (swatches in jar) not as the number of bacteria per ml of neutralizing solution. ‘0’ counts at $10^0$ dilution was reported as “less than 100”. The % reduction of bacteria by the specimen treatments was calculated using the following formula:

$$100 \frac{(B-A)}{B} = R$$  \hspace{1cm} (3.3)

where, R is the % reduction; A, the number of bacteria recovered from the inoculated treated test specimen swatches in the jar incubated over the desired contact period; and B, the number of bacteria recovered from the inoculated treated test specimen swatches in the jar immediately after inoculation (at ‘0’ contact time). The % reduction of bacteria by the specimen treatment against each test organism was reported for five fabric samples.
3.4.12 Coating Method for Phase Changing Material

To ensure thermoregulation in the multi layered mattress, a knitted fabric was micro encapsulated with a phase changing material. Method of application is described below.

Fabric samples are prepared, weighed, washed and rinsed with water. The required amount of PCM is mixed with one liter of water. The fabric samples are rinsed in water soaked in the prepared finish solutions for 30 min and then sent through padding mangle for uniform application of finish after which it is dried at 120°C and curing is done at 150°C without applying pressure.

3.4.13 Differential Strength Calorimeter for Analyzing PCM

The heat absorption and release capacity of micro encapsulated Phase changing material is measured by Differential Scanning Calorimeter (DSC). Properties measured by DSC instrument include thermal capacities, melting temperature of PCM, and crystallization temperature of phase changes of PCM microcapsules. Heating and cooling scans were carried out at the rate of 10° C/min in the temperature range of 0°C to 80°C. Experiments were performed under nitrogen environment by DS Q20 (TA Instruments).