ISSN 2229-5518

Development of Silicone Based Water-Resistant, Chemical Resistant Moisture Absorbent and Non - Ignitable Fabric

Dilan Vethandamoorthy, Eranda Mandawala, Wasana Bandara

Abstract— The focus of this study is on determining the optimum combination of components in coating material to obtain high water resistance and moisture absorbent properties. Silicone caulk and Mineral spirit were used in thirteen different combinations to coat the fabric along with one sample with one mixture for control. This method was discarded as water penetrated through the fabric under high pressure. Silicone caulk with Acrylic Matt Topcoat was used in thirteen different combinations to coat the fabric along with one sample with one mixture for control. Surface coated using a flat bottomed plastic rod and allowed 5 -6 hrs. for setting process. The fabric is a combination of Polyester-cotton blend, Chemical layer and Airmesh in the inner. Two variants of the fabric were produced as Single coated fabric and Double coated fabric. Single coated fabric was able to withstand Bundesmann Rainshower Test (ISO 9865:1991) and a Hydrostatic pressure (ISO 811:1981) more than 1.9m. The Double coated fabric did not ignite in the Flammability Test. The selected Con. Acids and Bases didn't penetrate the fabric but made some changes to the color of the fabric. The Direct Coating method was modified inorder to design the proposed fabric.

Index Terms— *Silicone caulk, Mineral spirit, Acrylic matt topcoay, Bundesmann Rainshower Test, Hydrostatic pressure, Double coated fabric, Flammability Test.*

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1 Introduction

Waterproof materials have an extraordinarily high use, with products for everyday clothing, sportswear and protective clothing for industrial or technical applications. Developing product's water proofing property is an important value added process that can be helpful in wide range of environmental conditions. The majority of the underwater projects, semi- submerged aquatic settings and in general weather protection services require waterproofing materials. (Shishoo, [35])

A waterproof and breathable fabric incorporates two distinct functions of 'waterproofness' and 'breathability'. It should basically provide protection from the rain, wind and cold but also maintain a comfortable microclimate just below the fabric layer. The idea of a waterproof fabric is not new; in very old times, people were also in need of such fabrics. (Özek, H. [28]) Because of their many desirable qualities, Polyester fibres and fabrics have many uses. Polyester is often used in outerwear because of its high tenacity and durability. It is a strong fibre and consequently can withstand strong and repetitive movements. Its hydrophobic property makes it ideal for garments and jackets that are to be used in wet or damp environments--coating the fabric with a water-resistant finish intensify this effect. (Polyester filament yarn, fiber and spun from quality sources. [29])

Silicone based materials are applied over porous surface in order to make it breathable and water – resistant. The most common varieties include siloxane, silane, and silicone rubber, which are appealing due to their effectiveness in penetrating substrates without compromising porousness. In addition to being silicon-based, these materials share a number of other characteristics, including a high level of breathability and the capacity for being applied to most products without noticeably altering their appearance. But despite their similarities, siloxane, silane, and silicone rubber products each have their own distinct attributes that affect how they are manufactured and used. (Waterproofing with Silicon-Based Materials. [41]). Silicones exhibit many useful characteristics, including low thermal conductivity, low chemical reactivity, low toxicity, thermal stability (constancy of properties over a wide temperature range of −100 to 250 °C), Does not support microbiological growth and resistance to oxygen, ozone, and ultraviolet (UV) light.(Silicone Basics - GT Products, Inc | Blvd Grapevine Texas. [36]).

It's important to distinguish between water proofing and water resistance before going in detail. Under much higher hydrostatic pressure water- proofing fabric are resistant to the penetration of water moreover these fabrics have fewer open pores and permit the passage of air or water vapor. Water resistant fabric are resistant to penetration of water, air and water vapor. Water resistant fabric is made by depositing a hydrophobic chemical layer on the fiber's surface. Water resistance requires filling the tiny small pores of the fabric. (Rowen, J., & Gagliardi, D. [30]).

1.2 Problem Statement

This study will provide an assessment of the effects of variation in the amount of Silicone caulk and Acrylic Matt Topcoat on water-resistant fabric.

Waterproofing breathable fabrics find applications in different market segments from regular apparel and special high performance apparel to technical textiles (G.Nalankilli, S. [12]). Different end products require different specifications and properties. Waterproof properties can be achieved using different methods like high density tight weaving, micro porous coating or lamination, and solid coating or lamination. However, use of solid polymer coatings has some advantages. For example, due to the continuous solid layer on the structure, there are no pores on the surface, which prevents the contamination and provides better water resistance (Lomax, R.G. [24]). To achieve the required specifications and properties like high water vapour transmission, high water resistance, greater strength, improved flexibility, and better durability, it is necessary to use an optimized combination of components in the coating. (Holmes, [18]).

This study will focus on establishing an optimum combination of Silicone caulk (hydrophobic) and Acrylic Matt Topcoat components to achieve the highest water-resistant properties.

1.3 Research Questions

- What are the raw materials to be added?
- What are the steps to be followed during the production of the water resistant fabric?
- How to determine the water-resistant property?
- How to determine the moisture absorbent property?
- How to design a method of application?

1.4 Research Objectives

Main objective:

- To determine the effect of the amount of Silicone mixture application on water resistant properties of the fabric.

I. Sub- objectives:

I. To determination of the raw materials required.
II. To determination of the steps involved.
III. To determine optimum combination of chemicals
IV. To study the water-resistant properties of the fabric
V. To design method of application.

1.5 Benefits of the Study

This study helps to determine the effective concentration and application of the Silicon mixture in order to produce water resistant fabric. This is a moderate cost production process. Silicone, because of its inherent composition, is used in making fabrics and is combined with fabrics to enhance the fabric's functional quality. Silicone does make a fabric more water / repellent which brings it quite close to being water proof. It also brings a kind of roughness, structure and more age to the garment in addition to being also heat resistant.

2 Literature Review

Clothing innovation is an important modern behavior that contributed to the successful expansion of humans into higher latitudes and various climates. According to the previous researches clothing was originated long ago though there are some archaeological, fossil or genetic evidences to support more specific estimates. As clothing evolved from the older ages, it was adopted by humans; the emergence of clothing may provide more specific estimates of the origin of clothing use. Bayesian coalescent modelling is a method for estimating past population dynamics through time from a sample of molecular sequences without dependence on a pre-specified parametric model of demographic history. This modelling approach was used to estimate that clothing lice diverged from head louse ancestors at least by 83,000 and possibly as early as 170,000 years ago. This analysis suggests that the use of clothing likely originated with anatomically modern humans in Africa and reinforces a broad trend of modern human developments in Africa during the Middle to Late Pleistocene. (Toups, Kitchen, Light, & Reed, [39]).

The first real textile, as opposed to skins sewn together, was probably felt. Surviving examples of Nålebinding, another early textile method, date from 6500 BC. The knowledge of ancient textiles and clothing has expanded in the recent past due to modern technological developments. The knowledge of cultures varies greatly with the climatic conditions to which archaeological deposits are exposed; the Middle East and the arid fringes of China have provided many very early samples in good condition, but the early development of textiles in the Indian subcontinent, sub-Saharan Africa and other moist parts of the world remains unclear. (Barber, Elizabeth Wayland [4])

From pre-history through the early middle ages, for most of Europe, the Near East and North Africa, two main types of loom dominate textile production. These are the warp-weighted loom and the two-beam loom. The length of the cloth beam determined the width of the cloth woven upon it, and could be as wide as 2–3 meters. The second loom type is the two-beam loom. Early woven clothing was often made of full loom widths draped, tied, or pinned in place. (Barber, Elizabeth Wayland [4])

Protective clothing is needed for working at temperatures below 4ºc. The selection of proper clothing should be made according to the conditions such as temperature, weather, the kind of activity performed and its duration. The use of shape memory polymers with their thermally sensitive response characteristics and phase change materials with their quick phase change responses to the environmental changes is being widely discussed with regard to the cold weather clothing. (Scott, R. A. [32])

Protective clothes are produced to protect the wearer against hazardous environments and/or chemical, biological, nuclear or similar threats. Protective clothes such as thermal protective clothes, active sportswear, military clothes, medical clothes and chemical protective clothes are expected to show some functional properties like fire resistance, resistance to certain chemicals, antibacterial properties etc. according to their individual end uses (Zhou, Reddy and Yang, [43]). In addition, one of the important shared characteristics of most of these clothes is waterproofness. Possessing waterproofness, these clothes serve as a barrier against rain or pressurized water, hazardous liquid chemicals and blood and other metabolic liquids which can cause infection, so they prevent these liquids to contact with the skin. For this purpose, waterproof or waterproof breathable coated and laminated fabrics are used insteadof classical fabrics. These fabrics have high waterproofness however when they are cut and sewn together to form a cloth, their waterproofness shows discontinuities at the seams. (Zhou, Reddy, & Yang,[43])

The fabric was vulnerable to changes in the weather, becoming stiffer in the cold and stickier in the heat. It was not especially good with wool, either, because that fabric's natural oil caused the rubber cement to deteriorate. Nevertheless, the waterproofing process was essentially sound and was improved and refined over time. It was considered effective enough to be used in outfitting an Arctic expedition led by 19th-century explorer Sir John Franklin. Although he enjoyed his greatest success and lasting fame for his waterproofing process, Macintosh was no one-trick pony. In his capacity as a chemist, he helped devise a hot-blast process for producing high-quality cast iron. (The Return of Mac: Reinvention of Mackintosh, [38]) It lacked the property of comfort in many ways. Comfort is defined as "A state of physical ease and freedom from pain or constraint" (Oxford dictionaries, [27]).

However, it can also be categorised as mechanical and thermal comfort. Thermal comfort can be assessed by the air permeability of fabric as well as its permeability to water and heat. Mechanical comfort can be evaluated by its handle, rigidity, tensile properties, and smoothness (Behera & Hari, [5]).

Mechanical and surface properties were determined for polyester, cotton, and polyester/cotton blend knit fabrics. The polyester fabric showed a higher resistance to tensile deformation than the cotton fabric, while the blend fabrics showed an intermediate resistance in accordance with the blend level. This behaviour was due to better packing efficiency of polyester fibres, resulting in a yarn with a higher modulus. In contrast, the trend was reversed in bending and lateral deformation behaviour. This is postulated to be related to higher residual stress in the fabrics due to the different creep behaviour of cotton fibres. The compression behaviour, friction behaviour, and contacting surface fibre counts all point to increasing numbers of surface fibres with increasing cotton content in the fabrics; however, the 50/50 polyester/cotton blend fabric showed almost an identical behaviour to the 100% cotton fabric, as was the case with transport properties. (Yoon, Sawyer, & Buckley, [42])

A waterproof and breathable fabric incorporates two distinct functions of 'waterproofness' and 'breathability'. It should basically provide protection from the rain, wind and cold but also maintain a comfortable microclimate just below the fabric layer. The idea of a waterproof fabric is not new; in very old times, people were also in need of such fabrics. Waterproof clothes and covering were needed for outdoor endeavours of all kinds from farming to sailing, for riding and for the military, as well as for various sports. (Özek, H. [28])

The definition of breathability is often being confused with water- permeability, wind penetration or clothing's ability to wick liquid water away from the skin; all of these processes are also referred to as breathability but they depend on entirely different fabric properties. The water- permeability is a critical factor of wear comfort, especially in conditions that involve sweating. This property allows the fabrics to be water-permeable, to have protection against wind and to be waterproof. The water- permeability of breathable-coated fabrics can be measured in several different methods determining with sweating guarded hotplate (skin model), cup method or inverted cup method. In several research works the above mentioned test methods have been compared. In these works it was concluded that the water- permeability measured with different methods can't be compared directly due to different testing conditions, measurement parameters and units of measurements. Breathability is very important as it prevents the accumulation of water or sweat near the body. Core body temperature required for the wellbeing of individuals is approximately 37 oC (Sen, [34]). Perspiration is produced when the body temperature exceeds the standard temperature of 37oC. This temperature is balanced by secretion of sweat. It is important that the garments help in passage of sweat from body to atmosphere. This is because, if a person is in a cold climate performing high activity wearing non-breathable clothing, he may suffer from hypothermia, and if he is in a hot and humid climate, he may suffer from heat stress (Scott R. A., [33]).

Based on their length, fibres can be divided into filaments or staples. Natural fibres generally have an uneven physical structure both in staple and filament form. The fineness, cross-sectional shape, mechanical properties and even the colour are different and vary from fibre to fibre. The variability among the fibres and their non-homogeneity are distinguishing features that provide unique properties to natural fibres. Even man-made fibres are now being produced with properties similar to natural fibres by using techniques such as texturalization.

The following part describes the researches and studies that have been conducted to address the challenges of developing waterproofing fabric.

1. Methods of developing waterproof breathable fabrics
- Different types of waterproof breathable fabric
- Advantages of coating over lamination
- Mechanism of transmission from fabric to atmosphere
- Methods of application of coating

2. Methods of evaluation of waterproof and breathable properties
3. Factors affecting properties of waterproof breathable fabrics

2.2 Methods of Developing Waterproof Breathable Fabrics

The initial introduction of the waterproofing fabric to the market were in the form of raincoats which were fabrics coated with crude rubber. This was introduced by Macintosh (Fan & Hunter, 2009). Since then waterproofing fabric has gone through lots of changes, one of the latest being incorporation of breathability for giving comfort and flexibility. Waterproofing breathable fabrics are divided into various categories based on the method of manufacturing. The following list contains different types of waterproof breathable fabrics based on the methods of development,

a. Tightly woven fabrics
b. Micro porous membranes or coatings
c. Solid membranes or coatings
d. Combination micro porous and solid coatings
e. Smart breathable fabrics
f. Incorporation of retro-reflective micro beads
g. Fabric based on biomimetic

a. Tightly woven fabrics

Tightly-woven fabrics and micro porous polymer membranes transmit water predominantly by a diffusion-controlled mechanism similar to air permeability. Apparently solid (i.e. non-micro porous) polymer films and fabric coatings which have much lower air permeability can also be designed with good water permeability. The hydrophilic mechanism involved is a combination of a physical process involving permanent or transient pores in the molecular structure, and an absorption-diffusion-desorption process which depends on the chemical composition of the polymer and is specific for water . (Lomax, R. G. [23]). This ensures that there are minimum pores in the fabric. When this fabric is inserted into water, the cotton fibres swell transversely and further reduce the pore size. Very high pressure of water is required to penetrate such fabric. The density of yarns is very high in such fabrics. Synthetic filament yarns can also be used in a similar way by using fibres that have inherent water repellent properties. However, they do not swell when inserted in water, and hence further coatings are required to obtain desirable results (Holmes,[18]).

b. Micro porous membranes or coatings

They have pores with diameter 1 micron. These types of membranes are having hydrophobic properties. (Kannekens, A. [20]). One example of microporous membrane is Polytetrafluoroethylene (PTFE). PTFE membranes are also widely known by their trade name Gore-Tex (Brzeziński, Malinowska, Nowak, Schmidt, Marcinkowska, & Kaleta, [6]).
The application the PTFE membrane on fabric creates about 1.4 billion tiny holes per square centimeter of the fabric. Actually these holes are smaller than raindrops but much larger than water molecule (Holmes, [18]). Following are the various methods adopted inorder to develop microporous coating and membrane,

- Wet coagulation
- Solvent extraction
- Melt blown technology
- Point bonding technology
- Radio frequency beam radiation

c. Solid membranes or coatings

These coatings usually produce thin hydrophilic films with no pores or holes. Modified polymers in them diffuse by molecular diffusion or by adsorption diffusion- desorption process (Fan, J., & Hunter, L. [11]). By combining hydrophobic and hydrophilic components solid membranes and coatings can be developed to obtain better properties (Lomax, R. G. [23]). One of the researchers has suggested that hydrophilic coatings and membranes can be developed using a combination of hydrophilic and hydrophobic urethane components to obtain better properties while maintaining other physical properties (Krishnan, [22]).

d. Combination micro porous and solid coatings

Combining the micro porous and hydrophilic membranes and coatings is the other method for developing the waterproof breathable fabrics. Here, the micro porous mesh or material is imbued with a hydrophilic material like polyurethane. In the case of coatings, hydrophilic finishes are applied over micro porous films that have been attached to the fabric. This ensures enhanced waterproofing capacity while not altering the breathability. (Roey, 1992) in the atmosphere get transmitted from the fabric to the atmosphere by following methods, (Das, B., Das, A., Kothari, V., Fanguiero [8])

1. Absorption, transmission, and desorption
2. Diffusion
3. Adsorption and transmission
4. Convection

The main advantage of coating over lamination is lamination both hydrophilic and micro porous shows low adherence to the fabric surface compared to coatings. These hydrophilic films have lower transmission ability (Krishnan, S. [22]).

The disadvantage of using lamination is they are more expensive and require experience to obtain accurate control over web tension (Kannekens, A. [20]). The waterproof breathable properties of the fabric can be altered by changing the number of layers of coating, thickness of the layer, and the type of coating. Coatings also impart better handle and drapability to the fabric, compared to the laminations (Kramar, L. [21]).

2.3 Methods of application to develop waterproof breathable fabric.

There are several methods developed in order to apply coating for fabrics. The correct method is selected based on availability of equipment, end use, cost, and efficiency. Following are the methods that can be used to apply coating for the fabric, (Singha, K. [37]),

1. Direct coating
2. Transfer coating
3. Hot melt extrusion coating
4. Calendar coating
5. Rotary Screen coating
6. Foamed and crushed foam coating

2.3.1 Direct coating

The liquid coating is applied to the fabric while being run at tension under a floating knife blade, the distance between the fabric and the knife blade determines the thickness of the coating. The blade can be angled and have different profiles to affect the coverage. For this process to be effective the liquid coating must be quite viscous in order to prevent it soaking through the fabric, the coating is then dried or cured. There are various techniques in which this mechanism can be used (Hall, M. E. [16]):

- Knife over roller
- Knife on air
- Knife over table
- Knife over rubber blanket

Direct coating is usually carried on tightly woven fabrics with smooth surfaces (Lomax, R. G. [23]).

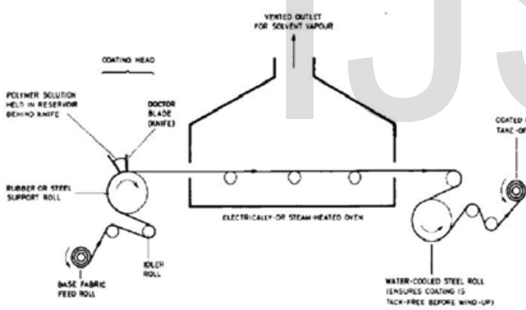


Figure 1: Direct Coating Method of Application (Lomax.[23])

2.3.2 Transfer coating

Transfer coated products are commonly called vinyls, or artificial leathers, the most common uses being in the furniture industry, general upholstery, and automotive interior trims.

The different qualities are measured and differentiated by their mass per square meter, measured in grams per square meter (gsm). Another differentiating factor in many transfer coated products is the thickness of the product, measured in microns. (Lomax, [23]).

2.3.3 Hot melt extrusion coating

In this method, only thermoplastic polymers can be used. Polymer granules are fed between heated rollers. When heated, the granules melt and spread onto the substrate (Hall, M. E. [16]).

2.3.4 Calendar coating

Calendar coating involves the fabric passing through a set of heated rollers to singe off any surface fibres, and afterwards will successfully add luster and smoothness to the fabric. Calendar coating is similar in principle to previously mentioned fabric coating processes, as the fabric passes through heated rollers. However, with this process, the coating is applied simultaneously to both sides of the fabric, with the thickness of the coating determined by the width of the nip between the rollers. If a thinner coating is more preferable, additional rollers should be used. (Singha, K. [37])

2.3.5 Rotary Screen coating

In this method, a screen consisting of perforated holes is used. The polymers are spread across the centre of the screen and then pressurized through the holes by a rotary blade (Hall, M. E. [16]).

2.3.6 Foamed and crushed foam coating:

Foam finishing was developed as a more environmentally friendly version of the pad-dry-cure coating system, as the chemical coating solution applied requires fewer products concerning weight, but equates to a high surface area. Foam Finishing Coating also ensures less wetting takes place, which will obviously require less drying. Furthermore, this coating process reduces waste pertaining to residual liquor. Foam Finishing Coating is useful when coating heavy fabrics, such as carpets, and can be used to effectively coat only one side of a fabric material. (Singha, K. [37]).

2.4 Development of Waterproof Breathable Fabrics

The development of the waterproof breathable fabrics helps to understand the role or the different parameters on the performance of the product in different conditions. In order to evaluate the various aspects of waterproofing and breathable properties various methods were adopted. During coating mechanical properties of the fabric is altered. (Sen, [34]).

Following are the different methods adopted to evaluate the waterproofing property of fabric.

1. Bundesmann rain tester (Holmes, [18])
2. AATCC 22 – Spray test (Ozen, 2012)
3. AATCC 127 – Hydrostatic Pressure Test (Ozen, 2012)
4. Contact angle – Using drop method [Goniometer] (Wang, Li, Jiang, Fang, & Tian, 2007; Rowen & Gagliardi, [30]).

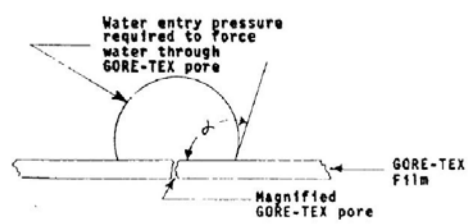


Figure 2: Schematic representation of water droplet on micro porous membrane (Gohlke & Tanner, 1976)

These are the different test methods which can measure the breathable property of fabric,
1. Evaporative dish method – ASTM E96-80 (Gretton, J. C., Brook, D. B., Dyson, H. M., & Harlock, S. C. [15])
2. Guarded Sweating Hot Plate method – ASTM F1868 (Huang, J., & Qian, X. [19]).
The different mechanical properties that can be measured in fabric,(Desai, V. M., & Athawale, V. D. [9]):
1. Tensile strength
2. Elongation at break
3. Stiffness
4. Abrasion resistance

2.5 Factors Affecting Properties of Waterproof Breathable Fabrics

Depending on the mechanism used to develop waterproofing fabric the properties of them differ. Some factors like yarn, type of fibre used and -modulus can affect the mechanical properties of the fabric. (Adler, M. M.,& Walsh, W. K. [2]). The construction of fabric and method of coating application has an effect on the breathable property of the fabric. (Lomax, [23])

Direct coating can be applied for nylon or polyester filament yarns. Cotton-polyester blends shows higher amount of transmission than nylon and polyester. The fibres under the coating also display hydrophilicity (Lomax, [23]). Importance of combining hydrophilic and hydrophobic components: In case of coatings and laminations, it is important to use the optimized combination of hydrophilic and hydrophobic materials. Hydrophobic components tend to lower the breathability of fabrics, however, showing excellent waterproof properties. On the other hand, hydrophilic components increase the breathability but are water soluble and hence non-durable. Hence the combination of hydrophilic and hydrophobic components is used to obtain desired water transmission and proper protection (Save, Jassal, & Aggarwal, 2005).
The experiment conducted by Wang and Yasuda, it was found that when the different fabric types were coated using hydrophilic and hydrophobic components, the fabrics with better wicking ability showed better water flux (Wang, C. X., Li, M., Jiang, G. W., Fang, K. J., & Tian, A. L. [40]). Quicker absorption of water and sweat from the body is observed when inclusion of hydrophilic fibres into fabric. In an experiment performed by Das et al., it was inferred that the use of certain proportions of viscose along with polyester led to quick absorption of sweat. However, as the proportion of viscose increased, the transmission of liquid from fabric to atmosphere decreased and the fabric was clogged with liquid (Das, Das, Kothari, Fanguiero, & Araujo [8]). Hence the proportion of hydrophilic component in the material should be optimum so that proper results are derived.

2.6 Test Methods

Various kinds of tests were performed to judge the waterproof, breathable, and mechanical properties of the coated fabric.

2.6.1 Spray Test (AATCC – 22) :

In this test, water was poured on the fabric in the form of a shower, and the water proofness of fabric was tested. A nozzle with two concentric rings of tiny holes was used 21 to create the spray. The outer ring had a 21-mm diameter and contained 12 holes. The inner ring had a 10-mm diameter and contained 6 holes; there was a hole at the center of the rings as well. The diameter of all the holes was 0.86mm each. A funnel with the nozzle attached to it was mounted on a stand. A plate was placed at a 45o angle at the bottom of the stand at a 150-mm distance from the nozzle. The fabric was attached in an embroidery hoop of 6-in diameter, such that there were no wrinkles on it. 250 ml of distilled water was poured through the funnel in about 25-30 s. The fabric was then compared to the chart (AATCC Standards [1], and ratings were given accordingly.

2.6.2 Contact Angle Test:

A goniometer was used to measure the contact angle between water droplet and fabric surface. The results were measured and recorded digitally. A clean syringe was filled with distilled water and mounted on the assembly that inserted pressure on the needle to release one water droplet at a time. This assembly helped in applying constant pressure in constant time to avoid any bias. The name of the machine and software was FTA 32. This was a video-based contact angle measuring system. The software was used to control and record the results. A fabric strip of about 1.5 to 2 in long and about 0.25 in wide was mounted below the needle assembly on a block that was positioned such that the drop fell exactly on the desired area of the fabric. Using the software, the syringe was "pushed" until it released the water droplet. This process was monitored on the computer screen.

The software captured about 50 picture frames of the water dropping on the fabric. The picture in which the water droplet was most stable was selected for analysis. The software then calculated the contact angle in that particular instance by drawing an arc over the droplet. Five readings were taken on each fabric strip.

2.6.3 Comfort Test:

The comfort test was one of the most important tests in this experiment. It helped to determine the and thermal resistance of the fabric. ASTM F1868-02 standard method was followed for this test (ASTM method F1868). The details of the machine are:
Make: MTNW incorporation
Serial No.: 223-21
Chamber: TPS Lunaire Climatic chamber
Chamber model: CEO 910-4
Fabric sample size required: 12 in x 12 in

This machine consists of a guarded sweating hot plate with pores and behaves like skin under dry and wet conditions. The plate is placed inside a chamber which maintains constant relative humidity (RH) and a constant temperature of 65% RH and 25°C. The sweating plate is maintained at body temperature 35 ± 5°C. Heat flows from the test plate to the sweating plate across through the fabric material and across to the test environment. This heat flow is measured in terms of thermal resistance values, that is, "clo" value, and also in terms of "m2 Pa/W" units.

First the thermal resistance that is dry test was performed. Initially, the bare plate thermal resistance was recorded and then the sample was mounted on the test plate to record the results. The sensors were securely connected to the controller for proper result recording. The wind sensor had to be at a 7-mm distance from the fabric sample. The height of the sensor could be adjusted by raising or lowering the plenum.

After the dry test, a wet test was performed. Distilled water was stored in a resource tank and was supplied to the test area through a small pipe. The test plate was wetted by pushing water through all the holes in it by pressing the pump. Mylar paper was also wetted and mounted on the sweating plate. The Mylar paper was secured using rubber tube on all four sides and by applying painter's tape on it. Extra water was removed using a sponge. Water gradually seeped through the topmost plate to the Mylar paper, stimulating sweating phenomenon. Bare plate resistance was first recorded. After that, fabric was mounted on top of the Mylar paper and secured using tape. The wind sensor was again adjusted to be at a distance of 7 mm from the fabric, and resistance of the fabric is recorded in terms of Ret (m2 Pa/W). During the whole process it was made sure that the RH and temperature were maintained at standard conditions.

2.6.4 Tensile Test:

The tensile strength test was performed to determine the breaking strength, or the amount of load a sample can withstand before breaking. This test was performed to review whether the coating and the coating process altered any of the mechanical or physical properties of the fabric. ASTM standard method D5035-95 method was used for this test. According to this test (ASTM method D5035), 4 samples each were cut in weft and warp directions from the fabric. The sample size was 9 in x 1 in. The sample was mounted in between the jaws, which were 6 in apart from one another. MTS software was used to control and record the results. The following are the machine and set-up details used:

Machine – MTS Tensile Tester
Principle – CRE (Constant Rate of Extension)
Software – MTS Test works
Distance between jaws – 6 in
Jaw speed – 12 in/min
Width – 1 in

The machine was calibrated at zero reading before beginning the test. With the help of the software, the machine was prompted to start the test. After the test was complete, the breaking force and elongation at break were recorded.

2.6.5 Stiffness Test:

The stiffness test was performed to check whether the samples gained undesirable rigidity after coating. A Taber Stiffness Tester was used to perform the test with ASTM standard method D 5342-97 (ASTM method D5342). Fabric samples of size 1.5 in x 2.75 in were used for the test. The stiffness tester had a dial, a pendulum, and a unit scale with markings in terms of angle. Initially the zero reading on the dial, unit scale, and pendulum were matched by adjusting the machine using screws at the bottom of the machine stand. The fabric was mounted between the clasps, carefully making sure that the clasps were at an equal distance from the center. The dial, unit scale, and pendulum were checked again for a zero reading.

The machine was turned on and the handle was rotated to the left side first until the 15-degree mark on the dial coincided with the zero reading on the unit scale. After that, the reading was taken at the mark where the pendulum pointed on the unit scale. After the left side reading was obtained, the handle was brought back to the center, and zero readings on all three components were adjusted to coincide. The handle was moved to the right, and readings were obtained in the same manner as for the left side.

All readings were measured in Taber stiffness units. Five readings each were taken for both left and right side for each sample.

2.6.6 Thickness Test:

The thickness test was performed to determine how many layers of thickness were added to the fabric due to coating. The thickness test also helped in measuring the evenness of the coating. If the thickness in one area is much greater than in another area of the coated material, it means that the coating is uneven and the other test results will be skewed. An electronic thickness tester, "Elektrophysik – MiniTest 600B" with standard 526 µm ± 1% plate, was used for this test. This tester had a display which showed the reading and a probe which had sensors. The probe was placed on the fabric sample and slightly pressed.

The display then showed the reading in terms of "µm." Ten readings were recorded on each fabric sample in different areas. It had to be made sure that the readings were taken in different areas of the fabric as it would eliminate bias and would help to determine if the thickness was uneven.

3 MATERIALS AND METHODS

3.1.1 Design of the Research

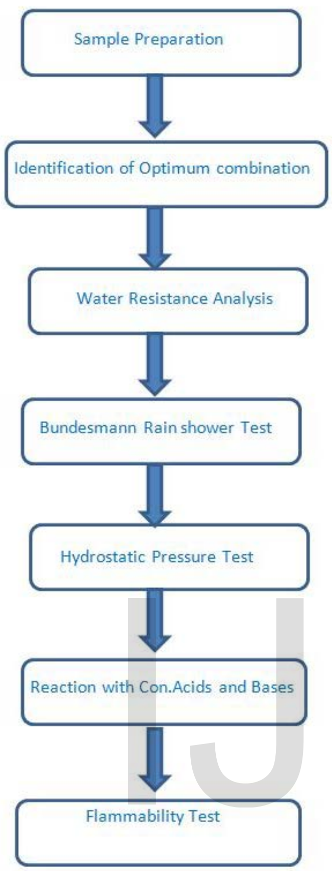


Figure 3: Research Design

3.1.2 Development of Silicone based water resistant moisture absorbent fabric

3.1.2.1 Materials

The following material was used to conduct the experiment:

- Fabric: Polyester (3.5inch X 3.5inch)
- Fabric composition: 60% cotton – 40% polyester

Polyester is one of the most commonly used fabrics in regular-wear apparel. Polyester has inherent hydrophobic properties and usually cannot absorb easily (Chaudhari, Chitmis, & Ramkrishnan, [7]).

The following chemicals were used in preparation of coating material:

1. Silicone Caulk – 100% RTV

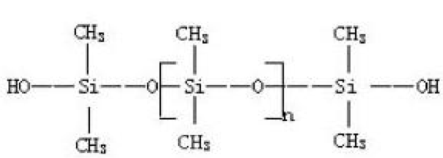


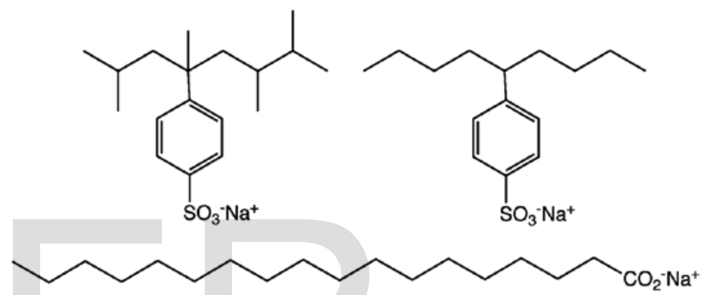
Figure 4: Structure of Silicone cailk(Beijing XinDeRuiJia PlasticCo,2016)

2. Surfactant – Mineral Spirit

White spirit or mineral spirits also known as mineral turpentine is a petroleum-derived clear liquid used as a common organic solvent in painting. (European Standards [10])

3. Washing powder

Laundry detergent, or washing powder, is a type of detergent (cleaning agent) that is added for cleaning laundry, commonly mixtures of chemical compounds including alkylbenzenesulfonates, which are similar to soap but are less affected by hard water. (Marek Lichtarowicz [26])



4. Hydrogen peroxide

Hydrogen peroxide is a chemical compound with the formula H2O2. In its pure form, it is a pale blue, clear liquid, slightly more viscous than water. Hydrogen peroxide is the simplest peroxide. (Hill, C. N. [17])

The components were used in varying percentages in the composition. In a research study carried out by Mukhopadhyay and Midha, various compositions of polymers were noted. The compositions contained the waterproof breathable component in the range of 15% to 45%. Hence, the below compositions were developed to derive the composition with optimum results. A total of 8 variations were selected based on both the previous studies and the probability of error that could occur.

5. Acrylic water base matt Topcoat

A novel acrylate-based copolymer containing keto-carbonyl, amide and carboxyl groups was prepared by emulsion polymerization (Gies, T. [14]). Polyurethanes are a class of versatile materials with great potential for use in different applications, especially based on their structure-property relationships. Their specific mechanical, physical, biological, and chemical properties are attracting significant research attention to tailoring for use in different applications. Enhancement of the properties and performance of PU-based materials may be achieved through changes to the production process or the

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raw materials used in their fabrication or via the use of advanced characterization techniques. (Akindoyo J, Beg, M., Ghazali, S., Islam, M., Jeyaratnam, N. and Yuvaraj, A.[3])

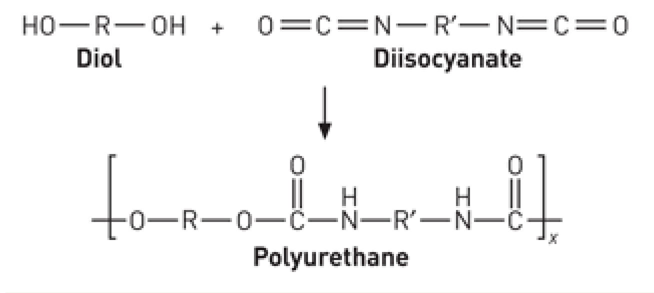


Figure 6: Formation of Polyurethane

The tough film provided by the top coat gives a long lasting protection from household stains, chemicals, abrasion and rain. This is odorless and environmentally friendly; these can be safely utilized in laboratory environments.

6. Air Mesh Fabric (Polyester)

Fabric polyester is made by the chemical synthetic fibre, it belongs to polyester system. Mesh polyester has advantage of solvent resistance, high temperature resistance, water resistance, chemical resistance. Although when the polyester mesh suffers much bigger external pressure, its physical performance is stable and stretchability is low. Compared with nylon mesh, it has poor wear resistance.

This can absorb the liquid and particulate from the environment into its tiny porous mesh membrane. This has a light texture so convenient to wash and sterilize good rebound elasticity and providing cushioning perfection, easy to wash and quick drying, non-toxic, moisture proof and mould proof and recyclable.

Figure 7: Air mesh Fabric (Polyester)

3.1.2.2 Research Instruments

- Volumetric flasks
- Measuring cylinder
- Plastic dishes
- Weighing scale
- Stirring rods
- Flat bottomed plastic rod
- Digital measuring scale (upto 0.01g)
- Thermocol sheet
- Pins
- Plastic beaker

3.1.2.3 Method - 01

3.1.2.3.1 Sample Preparation

A sample size of 3.5inch x 3.5inch Polyester fabric was made.

Digital measuring scale was calibrated properly before measuring the samples. Specified weight of Silicone caulk and the volume of and Mineral spirit were measured and before performing each trial. Mineral spirit was measured by using 50ml measuring cylinder.

After the application the fabric was placed in a flat thermocol sheet and attached with pins. Clean dust free environment was chosen inorder to prevent trapping of particulate matter during application of chemicals.

3.1.2.3.2 Cleaning

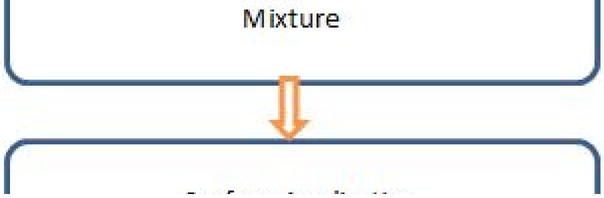
Washing powder was mixed in hot water and few drops of hydrogen peroxide were added and stirred well. The sample fabric was dipped in the hot water for several minutes.

3.1.2.3.3 Methodology

Totally 13 trials were performed in order to identify the optimum concentration required to resist the water penetration. Different combinations of Silicone caulk and Mineral spirit were combined by changing the weight of Silicone while keeping the volume of Mineral spirit constant.

The final mixture was applied on one surface of the fabric gently by using a flat bottomed plastic rod.

After application samples were placed in a clean dry environment for 6 -12 hrs of time for the setting process at standard atmospheric temperature (25^{o}c).



3.1.2.4 Method – 02

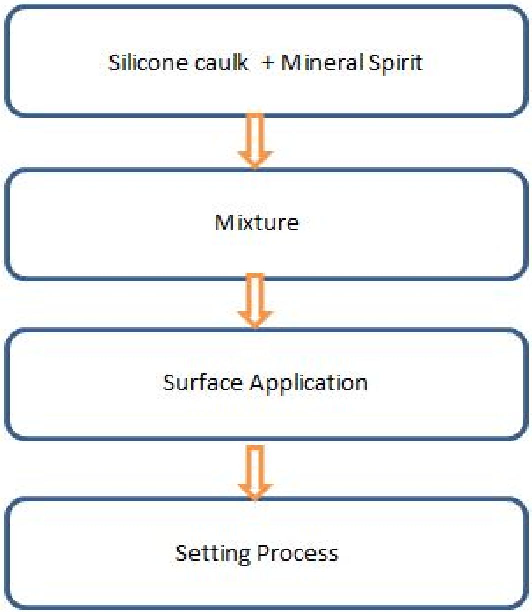


Figure 8: Flow chart for method 01

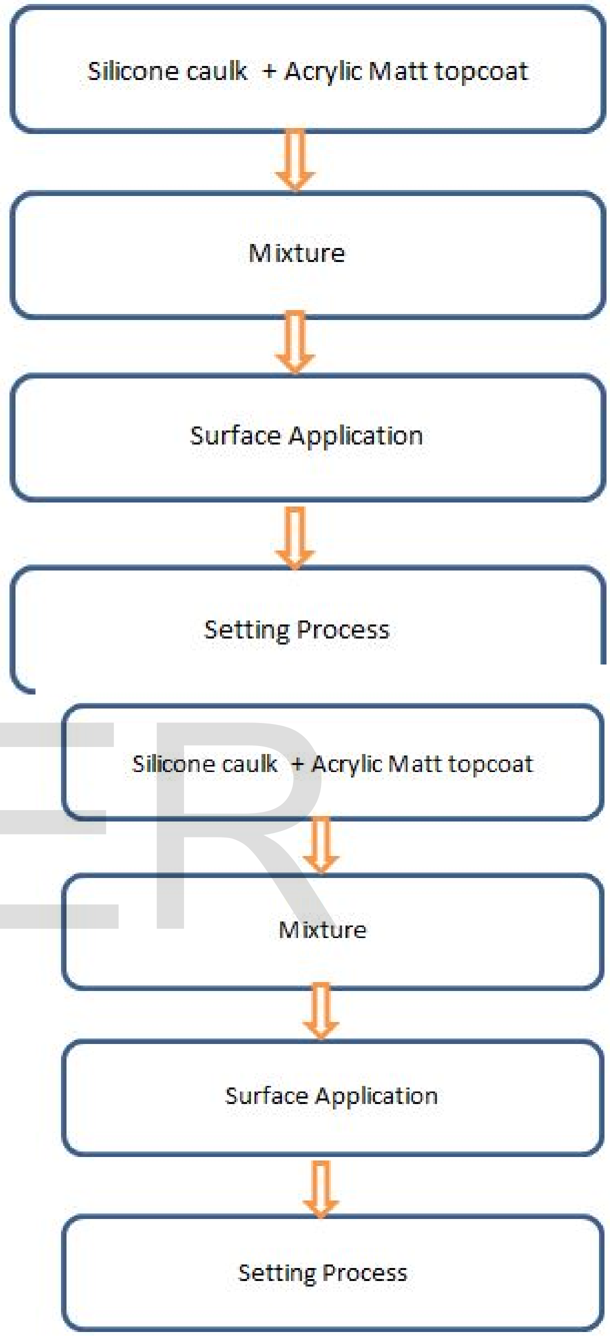


Figure 9: Flow chart for method 02

Stage 01 – Identification of optimum combination

Table 1: Combination of Trials

Trial	Silicone Caulk	Mineral spirit
13	8.0g	15ml
12	7.5g	15ml
11	7.0g	15ml
10	6.5g	15ml
9	6.0g	15ml
8	5.5g	15ml
7	5.0g	15ml
6	4.5g	15ml
5	4.0g	15ml
4	3.5g	15ml
3	3.0g	15ml
2	2.5g	15ml
1	2.0g	15ml

Fabric with all 13 combinations was tested inorder to meet the water repellence and resistance properties in certain districts of Srilanka. Jaffna and Badulla districts were chosen for the above procedure. Each fabric was tested for 7 days in a time interval of 8am-12am in the morning and 2pm – 8pm in the evening. A small drop of water droplet was dropped within a specific time interval to test the water repellence and resistance according to different environmental conditions.

After application samples were placed in a clean dry environment for 4 -6 hrs of time at standard atmospheric temperature (25^{o}c) for the setting process.

Stage 01 – Identification of optimum concentration

Table 2: Combination of Trials

Trial	Silicone Caulk	Acrylic Matt Topcoat
13	8.0g	5.0g
12	7.5g	5.0g
11	7.0g	5.0g
10	6.5g	5.0g
9	6.0g	5.0g
8	5.5g	5.0g
7	5.0g	5.0g
6	4.5g	5.0g
5	4.0g	5.0g
4	3.5g	5.0g
3	3.0g	5.0g
2	2.5g	5.0g
1	2.0g	5.0g

3.1.2.4. Samples of the Trial

Figure 10: Sample 01
Silicone – 3.5g
Acrylic matt Topcoat – 5.0g

Figure 11: Sample 02
Silicone – 4.0g
Acrylic matt Topcoat – 5.0g

Figure 13: Sample 03
Silicone – 5.0g
Acrylic Matt Topcoat – 5.0g

Figure 12: Sample 04
Silicone – 8.0g
Acrylic Matt Topcoat – 5.0g

3.1.2.4. Bundesmann rain-shower test (ISO 9865:1991)

Bundesmann Rain Tester used for determination of water repellency of fabrics to the rain-shower method. Test specimens of the fabrics under test are simultaneously exposed to a simulated heavy rain shower. The water repellency of the fabric is assessed by comparison of the wet fabrics to a standard chart. The water absorbed by the specimens is determined after the test is over which is the measure for resistance to wetting. It consists of 4 specimen holders of 100mm diameter cups. Rain is produced by 300 pieces nozzle and falls down from 1500mm height from the fabrics. It is set with the centrifuge device. (Gateslab.com. [13]).

A sample size of 18 x 18 inch fabric was made inorder to test for the Bundesmann rain-shower test.

This chemical combination of 4g of Silicone with 5g of Acrylic matt Topcoat (3.5inch x 3.5inch) was calculated for 18inch x 18inch.

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Table 3: Chemical Composition

Sample size	Silicone	Acrylic Matt Top-coat
3.5inch x 3.5inch	4g	5g
18inch x 18inch	106g	132g

The amount calculated for 18inch x 18inch fabric was placed in a plastic vessel and mixed efficiently by using an electric beater. After the mixing the solution was evenly distributed on the fabric. Then by using a flat bottomed plastic rod the solution was applied to the whole surface. Finally the applied fabric was placed in a clean dry place for setting.

Figure 15: Mixing the chemicals by using electric beater

Figure 14: Even distribution of solution on the fabric sur face

Figure 16: Fabric after the application of solution

3.1.2.4.5 Hydrostatic Pressure Test (ISO 811:1981)

This test method measures the resistance of a fabric to the penetration of water under hydrostatic pressure. It is applicable to all types of fabrics, including those treated with a water resistant or water repellent finish. Water resistance depends on the repellency of the fibers and yarns, as well as the fabric construction. (Safequipment.com, [31])

Specific tests requiring conditioning have been carried out at standard atmospheric conditions (20 + 2oc temperature, 65 + 4 % relative humidity) as stipulated in ISO 139:2005.

Temperature of water 20oc

Rate of the increase of water pressure – 10mm/seconds.

A sample size of 18 x 18 inch fabric was made inorder to test for the Hydrostatic Pressure Test. Totally 3 specimens from the sample were tested.

3.1.2.4.6 Flammability Test (16 CFR 1610)

Flammability of Wearing Apparel - 16 CFR 1610 - (45 Degree Flammability)

The United States Federal Government requires clothing and textiles intended to be used for clothing to have Normal Flammability (Class 1) as tested with 16 CFR 1610 (ASTM D 1230 Standard Test Method for Flammability of Apparel Textiles). Fabric is mounted at a 45° angle from ignition source. (Manufacturingsolutionscenter.org, [25])

Specific tests requiring conditioning have been carried out at standard atmospheric conditions (20 + 2oc temperature, 65 + 4 % relative humidity) as stipulated in ISO 139:2005.

A sample size of 18 x 18 inch fabric was made inorder to test for the Hydrostatic Pressure Test. Totally 5 specimens from the sample were tested.

4 Results and Discussion

4.1 Test Results

4.1.1 Bundesmann Rainshower Test (ISO 9865:1991)

Particulars of item – one sample of item 2 pieces

Result - Satisfactory (No penetration of water through the fabric)

4.1.2 Hydrostatic Pressure Test (ISO 811. 1981)

Particulars of item – one sample of item 3 specimens

Result - More than 190 (Water is not penetrating through the fabric from a maximum height of 2m)

4.1.3 Flammability Test (16 CFR 1610)

Direction – Lengthwise and Widthwise

Table 4 Flammability Test

Sample	Burn code(Black color side) / Class 1
Specimen 1	DNI
Specimen 2	DNI
Specimen 3	DNI
Specimen 4	DNI
Specimen 5	DNI

DNI – Did not Ignite
Class 1 – Normal Flammability of Commercial Standard 16CFR 1610. Formerly 191-53 of United States flammability Fabric Act. Textiles exhibit normal flammability and are acceptable for use in clothing.

4.2 According to method 1,

Trial 1 - 5
Upto the 5th trial the final combination made by mixing the Silicone and Mineral spirit wetted the fabric resulting in sealing the tiny holes of the fabric. This fabric had both water repellent and water resistant property. When water is pressurized continuously for specified period of time the fabric lost its water repellent and resistant ability.

Trial 6
At the combination of 4.5g of Silicone with 15ml of Mineral spirit wetted the fabric resulting in sealing the tiny holes of the fabric. This fabric had both water repellent and water resistant property. When water is pressurized continuously for specified period of time the fabric was able to withstand the water repellence and resistance compared to previous trials but it lost its properties after specific period of time.

Trial 7-13
From 7 – 13 the final combination made by mixing the Silicone and Mineral spirit wetted the fabric resulting in sealing the tiny holes of the fabric. This made the texture and the appearance of the fabric to change. Moreover white color spots were observed in the fabric. This combination made the fabric more rigid thus this combination was discarded.

Inorder to check the water repellence and resistant with the change in the climatic conditions, Badulla and Jaffna districts was chosen. As Jaffna has hotter climatic condition while Badulla has a normal/ average climatic condition.

Trial 1 was unable to withstand the climatic conditions in the Jaffna District while all other combinations were able to withstand. In Badulla district all the combinations were able to withstand the climatic conditions.

Although these combinations were able to withstand the environmental conditions in Badulla and Jaffna district except trial 1, under pressurized water application all of the fabric lost its water repellence and resistant properties. Moreover a small scratch in the fabric surface causes the water particles to penetrate, So this method was discarded.

Table 5: Results of method 01

Trial	Silicone Caulk	Mineral spirit	Result
13	8.0g	15ml	+
12	7.5g	15ml	+
11	7.0g	15ml	+
10	6.5g	15ml	+
9	6.0g	15ml	+
8	5.5g	15ml	+
7	5.0g	15ml	+
6	4.5g	15ml	+
5	4.0g	15ml	+
4	3.5g	15ml	-
3	3.0g	15ml	-
2	2.5g	15ml	-
1	2.0g	15ml	-

4.3 According to the method 2,

Trial 1 -4
Upto the 4th trial the final combination made by mixing the Silicone and Acrylic Matt Topcoat penetrated the tiny holes of the fabric and resulted in change in the texture of the fabric. As a result these combinations were discarded.

Trial 5
At the combination of 4g of Silicone with 5g of Acrylic Matt Topcoat gave good water resistant ability with good flexibility without penetrating through the fabric. Moreover the combination did not affect the appearance of the fabric. This combination was easier to distribute and apply throughout the fabric as the viscosity is lower when compared to the higher combinations.

Trial 6-13
From 6 – 13 the final combination made by mixing the Silicone and Acrylic Matt Topcoat had good water resistant ability but it made the fabric more rigid and less flexible. The mixing of the chemicals became tougher as the viscosity was increasing during each trial. Moreover it increased the final weight of the fabric as the weight of the Silicone increase.

Table 6: Results of method 02

Trial	Silicone Caulk	Acrylic Matt Top-coat	Result
13	8.0g	5.0g	+
12	7.5g	5.0g	+
11	7.0g	5.0g	+
10	6.5g	5.0g	+
9	6.0g	5.0g	+
8	5.5g	5.0g	+
7	5.0g	5.0g	+
6	4.5g	5.0g	+
5	4.0g	5.0g	+
4	3.5g	5.0g	+
3	3.0g	5.0g	+
2	2.5g	5.0g	+
1	2.0g	5.0g	+

Stage 2 -Developing the Fabric

Trial 5 was chosen to develop the product. The combination of 4g of Silicone with 5g of Acrylic Matt Topcoat was weighed by using an electric balance. As the sample size is small mixing was done by stirring by hands. The prepared mixture was evenly applied on to one surface of the fabric by using a flat bottomed plastic rod.

After the application, Air mesh fabric layer was placed on the top of the mixture inorder to adhere with it.

After application samples were placed in a clean dry environment for 4 -6 hrs of time for the setting process.

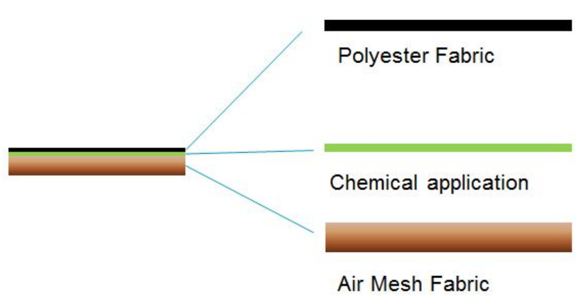


Figure 17: Fabric Design

4.4 Reaction with Acids

Samples of 1.5 x 1.5inch sizes of fabric with Polyester cotton blend and the chemical layer without the Airmesh were treated with Con. Sulphuric(98%), Con. Nitric acid(63.01%), Con. Hydrochloric acid(38%) and Glacial acetic acid(90%).

(Airmesh removed fabric was used inorder to clearly determine the penetration)

Table 4: Reaction with Acids

Acid	Penetration	Color change
Con. Sulphuric (98%)	-	+
Con. Nitric Acid (63.01%)	-	+
Con. Hydrochloric acid (38%)	-	-
Glacial Acetic Acid (90%)	-	-

4.6 Developing a method of Application

Direct coating method is an older method that is used in application of Polymeric compounds on the surface of the fabric. Inorder to make the proposed fabric initially Silicone based polymeric compound should be applied onto the fabric surface and then the Airmesh fabric should be fused with the solution inorder to make the combined final fabric.

Some alternations were made to the existing Coating process by adding some Rollers, beds and inlets. Secondary Fabric Feed Roll was introduced inorder to supply the Airmesh fabric into the coating process. An Idler Roller was introduced inorder to support the fabric to move into the Combining Inlet to adjoin the fabrics together. This combined fabric moves inside a uniform steel bed inorder to maintain uniformity in the Fabric.

5 Conclusion

Silicone with Mineral spirit combination was discarded as the fabric lost its water repellency and water resistant properties with pressurized water.

The combination of 4g of Silicone with 5g of Acrylic Matt Topcoat gave good water resistant ability with good flexibility without penetrating through the fabric. So this method was adopted for developing the fabric.

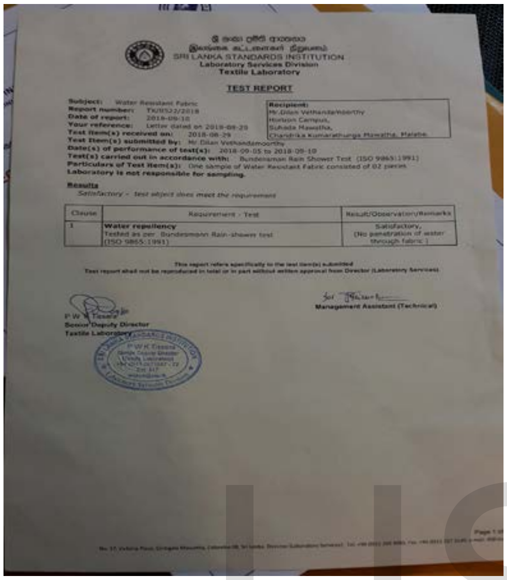
The fabric provides along lasting protection from household stains, chemicals, abrasion and rain, moreover this is odorless and environmentally friendly. The chemical layer in the middle of the fabric acts as an insulator for heat.

Two variants of the fabric were developed as single coated fabric and double coated fabric according to the chemical application. Single coated fabric was able to withstand a hydrostatic pressure of more than 1.9m and Bundesmann Rainshower Test. The double coated fabric did not ignite in Flammability Test. Moreover most of the con. Acids and bases did not penetrate both of the fabric but resulted in few alternations.

A proper method for the Coating process was designed by introducing Secondary Fabric Feed Roll, An Idler Roller, Combining inlet and uniform steel bed into the Direct Coating method.

6 Appendix

6.1.1 Bundesmann Rainshower Test (ISO 9865:1991)



SRI LANKA STANDARDS INSTITUTION
Laboratory Services Division
Textile Laboratory

TEST REPORT

Subject: Water Resistant Fabric
Report number: TX/0522/2018
Date of report: 2018-09-18
Your reference: Letter dated on 2018-08-29
Test item(s) received on: 2018-08-29
Test item(s) submitted by: Mr Dilan Vethandamoorthy
Date(s) of performance of test(s): 2018-09-05 to 2018-09-10
Test(s) carried out in accordance with: Bundesmann Rain Shower Test (ISO 9865:1991)
Particulars of Test item(s): One sample of Water Resistant Fabric consisted of 02 pieces
Laboratory is not responsible for sampling.

Recipient:
Mr.Dilan Vethandamoorthy
Horizon Campus,
Suhada Mawatha,
Chandrika Kumarathunga Mawatha, Malabe.

Results
Satisfactory - test object does meet the requirement

Clause	Requirement - Test	Result/Observation/Remarks
1	Water repellency Tested as per Bundesmann Rain-shower test (ISO 9865:1991)	Satisfactory, (No penetration of water through fabric)

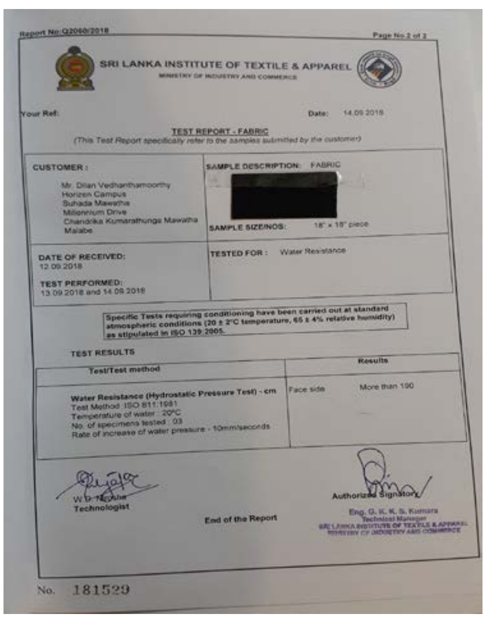
This report refers specifically to the test item(s) submitted
Test report shall not be reproduced in total or in part without written approval from Director (Laboratory Services)

P W K Tissera
Senior Deputy Director
Textile Laboratory

Management Assistant (Technical)

Figure 18: Bundesmann Test Report

6.1.2 Hydrostatic Pressure Test (ISO 811:1981)



Report No:Q2060/2018 Page No 2 of 2

SRI LANKA INSTITUTE OF TEXTILE & APPAREL
MINISTRY OF INDUSTRY AND COMMERCE

Your Ref: Date: 14.09.2018

TEST REPORT - FABRIC
(This Test Report specifically refer to the samples submitted by the customer)

CUSTOMER :
Mr. Dilan Vedhanthamoorthy
Horizen Campus
Suhada Mawatha
Millennium Drive
Chandrika Kumarathunga Mawatha
Malabe

SAMPLE DESCRIPTION: FABRIC
SAMPLE SIZE/NOS: 18" x 18" piece

DATE OF RECEIVED:
12.09.2018

TEST PERFORMED:
13.09.2018 and 14.09.2018

TESTED FOR : Water Resistance

Specific Tests requiring conditioning have been carried out at standard atmospheric conditions (20 ± 2°C temperature, 65 ± 4% relative humidity) as stipulated in ISO 139:2005.

TEST RESULTS

Test/Test method	Results	
Water Resistance (Hydrostatic Pressure Test) - cm Test Method :ISO 811:1981 Temperature of water : 20°C No. of specimens tested : 03 Rate of increase of water pressure - 10mm/seconds	Face side	More than 100

Technologist

Authorized Signatory
Eng. G. K. K. S. Kumara
Technical Manager
SRI LANKA INSTITUTE OF TEXTILE & APPAREL
MINISTRY OF INDUSTRY AND COMMERCE

End of the Report

No. 181529

Figure 19: Hydrostatic Pressure Test

6.1.3 Flammability Testing (16 CFR 1610)

SRI LANKA INSTITUTE OF TEXTILE & APPAREL

TEST REPORT - FABRIC

CUSTOMER :

SAMPLE DESCRIPTION: FABRIC

SAMPLE SIZE/NOS:

DATE OF RECEIVED:

TEST PERFORMED:

TESTED FOR : Flammability Test

Technologist

Authorized Signatory

182689

Figure 20: Flammability Test

TEST RESULTS

Test/Test method	Results
Flammability Test Test Method 16 CFR 1610	

Technologist

Authorized Signatory

End of the Report

SRI LANKA INSTITUTE OF TEXTILE & APPAREL

187355

Figure 21: Flammability Test

6.5 Developed Fabric

6.5.1 Single coated Fabric

Figure 35: Face side

Figure 37: Inner side

6.6 Modified Direct Coating Method of Application

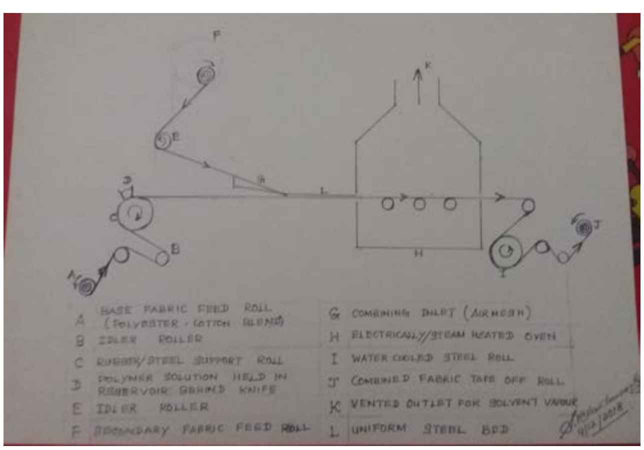


Figure 38: Modified Direct Coating

7 Acknowledgement

I would like to express my deep gratitude to, Mr. Eranda Mandawala and Mrs. Wasana Bandara, for guiding me from the inception of this Research to writing of the proposal. Her recommendations and insights have helped me to improve my knowledge about the subject and my research skills. Without her input and support, this dissertation would not have been possible.

I would also like to thank Mr. Sunesh Hettiarachchi for helping in the execution of my Research proposal and giving valuable insights on the subject. I greatly appreciate the help throughout the whole process of my thesis and for their continuous guidance and suggestions, which helped me to understand the concepts and clear my doubts.

————————————————

- *Dilan Vethandamoorthy is a graduate of BSc Biotechnology in Nilai University, Malaysia, E-mail: dilan.vethandamoorthy@gmail.com*
- *Eranda Mandawala is a Senior Lecturer in Faculty of Science Horizon Campus Malabe, Srilanka, E-mail: eranda@horizoncampus.edu.lk*
- *Wasana Bandara is a Lecturer in Faculty of Science Horizon Campus Malabe, Srilanka, E-mail: wasana@horizoncampus.edu.lk*

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