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BREATHABLE AND WATERPROOF COATED TEXTILES

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ABSTRACT

Demands for textiles that can impart hydrophobic qualities have increased greatly over the years as their application has become more prevalent in many industries. Their production can be based either from fabric construction or chemical applications such as coatings and laminates. This experimental work focuses on the use of coatings technology to produce cotton materials that would be both water repellent and breathable. It analyses the effects of using different treatments on the cotton materials samples. Finishes include paste and foam coats with Acrylic/Polyutherane compounds, as well as Pretreatment and post treatments with fluorocarbon based compounds. Applications were done using standard coating methods such as knife on roller and air blade techniques. The experiments also accounts for the different porosity values that cotton fabrics have, and how they affect the air and water permeability of the coated materials.

LIST OF FIGURES

1 INTRODUCTION

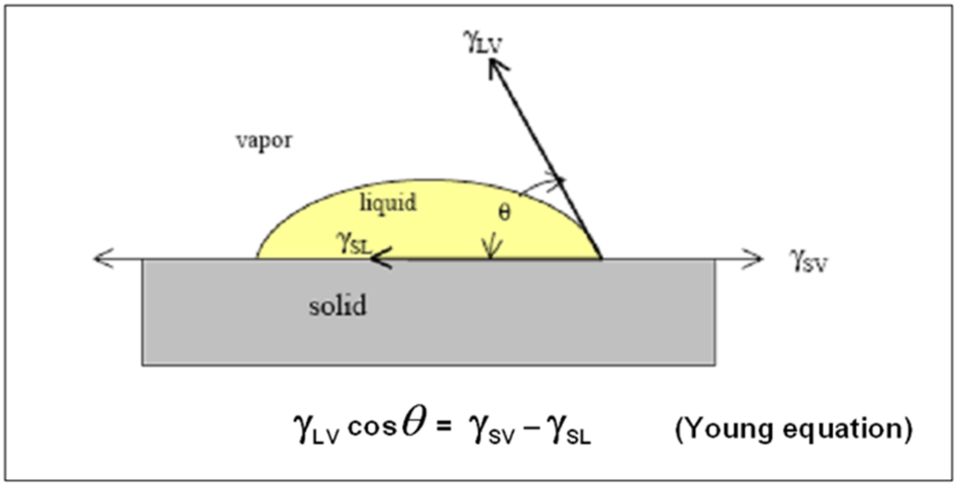
The ideologies of creating textiles that can impart hydrophobic properties have been around for thousands of years. History has found evidence of people in Ancient civilizations creating materials for basic products such as carriage bagsthat can be deemed waterproof. In today's modern lifestyle, the demands for such products have become more prevalent. Their applications can be found across various industries from creating high functional garments, to protective outdoor applications, and even in construction of building materials like in brand new sports arenas. This increased consumer demand for such goods puts pressure on textile manufacturers to continually grow and improve existing technologies. Design of textiles that are having this desired property of water repellence can be done either compacting the weave structure or applications of hydrophobic coatings or laminates on the surface of the fabric. Each technique can provide a different level of repellence and breathability in the final product, and choice over which procedure to use is dependent on specifications created by clients, consumers and governed protocols. This experiment postulates the impacts of using different coating finishes on cotton material samples in terms of their water resistance and breathability. It also considers the effect of utilizing cotton fabrics that have different porosity values on the level hydrophobicity when the materials have been chemically coated.

2 THEORETICAL REVIEW

2.1 HYDROPHOBICITY

This is a phenomenon whereby textile materials can repel water when the two come into contact with each other. Water would tend to flow off a hydrophobic fabric instead of collecting and seeping into the material. Determining whether a material is hydrophobic or hydrophilic (attracts the water molecule) can be done by examining the fabrics ability to wetting. Wettability can be defined as a textiles capacity to withhold a liquid onto a solid surface by means of their intermolecular forces that they possess. These forces are given the adhesive and cohesive forces of the solid and liquid. If there is a strong adhesive force, the liquid would spread onto the material, whilst if there strong cohesion, the drop of liquid would ball up and roll of the surface. The concept of wettability can pertain to all liquids not just water. When considering the effects of water the terms hydrophilic can be used to describe a wettable surface and hydrophobic a substrate that is non wettable.

A way to evaluate if a material is hydrophobic is by measuring the contact angle created when a drop of water is placed on the substrate surface. Wetting in textiles considers the interactions between the liquid, solid and air phases. Utilizing Young's equation to measure the contact angle in terms of the surface tension in the solid/liquid interface and the solid/air interface, the wettability of a material can be determined. The equation (given below) is taken from the thermodynamic equilibrium between the three phases, solid, liquid and gas at the point of contact between the drop of water and textile substrate. It shows that at equilibrium the chemical potential is equal to zero, where γ_{sv} is the solid vapour interfacial energy and γ_{lv} is the liquid vapour interfacial energy. The θ measures the contact angle which determines the wettability of the material. If the contact angle is low i.e. an acute angle the textile has high wettability whilst a high angle i.e. an obtuse angle, indicates low wettability. The picture below illustrates this principle.



γ_{LV} = liquid-vapor interfacial tension or surface tension

γ_{SV} = solid-vapor interfacial tension, not true surface energy

γ_{SL} = solid-liquid interfacial tension

θ = contact angle (angle liquid makes with solid surface)

Figure 1: Measurement of contact angle

Textiles created from synthetic materials tend to have a better ability to repel liquids as the polymeric derivatives in the yarns tend to be naturally hydrophobic. However, in natural yarns such as cotton, the material is hydrophilic and attract the water molecules. The industry makes a distinction between the levels of hydrophobicity that materials can possess. When a textile is deemed to be waterproof, the implication is that no water can pass into the material but at the same time, water vapour can’t escape through. This type of textile can be particularly necessary in applications such as umbrellas and building materials.

Water repellent textiles are those materials that can resist the impact of water whilst simultaneously having the ability to allow moisture transfer through the fabric. These materials are particularly important in garment production as it is necessary to have adequate ventilation in clothing so as to have good thermal comfort. The air flow properties of a textile material can be described as a fabric’s breathability. Air is needed to flow through a material to allow the ventilation and perspiration needs to be removed from the body to keep it cool. It is necessary to remove all water vapour from the body as quickly as possible especially for functional clothes such as for active sportswear, as excess sweat can gather in the clothes causing it to become wet and heavier for the user/athlete.

2.2 WATERPROOF AND BREATHABLE MATERIALS

There are three main ways in which fabrics that are both waterproof and breathable can be manufactured. Each method can produce a different level of hydrophobicity but it can also be dependent on the properties of the individual fibers in the material. The first type of fabric is densely woven materials. These are textiles with yarns (either natural or synthetic) that have been woven in such a way that the interstices between the yarns can't be seen. During weaving of these materials the weft and warp are created such that the pore space between them are small enough to not allow any water to penetrate through the material, but the pores are big enough to allow air and moisture vapour to pass through. A special kind of densely woven fabrics can be made using Microfibers; which are fibers that are less than 1 dtex per fibre are produced by specialized spinning techniques or by post treatment after spinning. These fibers are ideal for creating such functional properties in the end product [22]. High density fabrics transmit water vapour according to Fick's law of diffusion. This law states that that the fluctuations in $F_x$is proportional to the concentration gradient according to the equation below: $F_x = - D (\delta_c/\delta_x)$ where Fxis the amount of vapour that is diffused across an unit area per unit time. D is the diffusion constant and is the concentration gradient. The diffusion constant remains the same when there are changes in vapour concentration in the polymer or changes in the temperature. Water vapour in micro porous structures is thus dependent on vapour pressure gradient. However this only applies to steady state conditions. Fick's diffusion law is not satisfied by hydrophilic materials [7].

The second way to create breathable waterproof textiles is by applying a hydrophobic layer onto the material. This can be done by lamination. Laminates are membranes that can be adhered unto a fabric by means of heat or pressure. The membrane can be either porous or non-porous depending on the desired product use. These fabrics have the functional barrier are applied onto the textile substrate by adhesion such as heat or pressure. The laminate is usually a polymeric film or membrane. It is possible to have different porosities on the film making some more breathable than others. Three main types of laminates exist; micro porous laminates which have excellent breathability as they contain holes in them. It can be created in a coagulation process or photo polymerisation process and is typically found in products such as GORE-TEX and in Teflon laminates. The second type is a hydrophilic laminate which is created via extrusion. The final type is a combination between both properties and is used in a product called ‘Thintech’ by the 3M Company which uses a micro porous matrix of polyolefin and is impregnated in a hydrophilic polyutherane.

The third method is to coat the material which a polymeric resin. This method is similar as it also involves the application of a hydrophobic layer unto the surface of the textile. However, in coating the chemical is generally applied in liquid form directly onto the fabric and thereafter it can be dried in a stentor. It is possible to use solid and gaseous materials as well. This type of breathable and waterproof textiles will be elaborated in the following pages.

2.3 THE PROPERTIES OF COTTON

Cotton is the most widely utilized natural fiber in textile applications around the world. It is cultivated from seeds of the cotton plant in a process known as ginning. This procedure removes the fibers from the seeds which are then further processed to create bales. Generally the length of each fiber can range from around 0.9 inch to 1.6 inches. They are classed according to the staple length, grades and character. The baled fibers are used in textile manufacturers to be spun into yarns by either ring or rotor spinning. The fineness of cotton fibers are usually around 18 microns with long staple fibers- less than 15 microns.

Cotton yarns are then woven or knitted together to produce the desired material, which can be either pure cotton or blended with other yarns, generally synthetics such as polyester. The fabric construction plays a major role in determining the final properties that the resultant material will have. The breathability of a fabric is dependent on the weave structure. A more densely woven fabric has more resistivity to water than a material that is less dense. Weaving can be one of three designs, plain, twill and satin. The pore space between the warp and weft can be useful in determining the air flow of the material as well as moisture transfer.

Cotton exhibits good absorbency properties. This is particularly useful for clothing to allow the user comfort by picking up the sweat produced during activities. This characteristic also enables good static electricity properties in cotton, meaning that the clothes don’t stick to the body when wet. Generally, the have good stability and don’t shrink unless it is under a high tension applied to the yarn and fabric construction. The downside of cotton fabrics is that they are not very durable and can easily deteriorate over time. It can decompose when open to the elements such as extreme cold causing it to become hard and brittle. It can also be damaged by mildews, moths and silverfish. During cotton fabric production is common that the material undergoes many different chemical treatments to improve the material. Fibers are typically pre-treated by sizing and desizing which is a process to add and remove starch which aids in improves the qualities. The cotton is also mercerized. Mercerization is a process of whitening the cotton fabric and also it improves fabric luster and wettability. It allows for better fiber swelling [10].

2.4 COATINGS TECHNOLOGY

A Coating is the application of a polymeric resin unto a fabric surface to impart a barrier between the material and external forces. In textiles various different coats can be applied onto fabrics to create materials that have specialized functions for example, coats can be applied to create flame retardants, oil repellence, anti static behaviour and water repellence. It is applied in the finishing stages of the textile manufacturing process after the materials have been constructed. This is important as the type of coat applied is dependent on the fibers used in manufacture so as to produce a desired property in the final textile material. The coats applied must be durable and withstand the effects of as abrasion, washing and exposure to UV, toxic chemicals or fumes. The picture below depicts how a typical coat would appear on top of a textile substrate. Currently, there are a variety of coating products on the market, each with their own specification, designed purposely for the end use of the textile. The coat can be a liquid paste that is easily spreadable, and viscosity can be controlled to have exact depth of penetration for a specific fabric. A foam coat has air mixed into the chemical finish structure. The incorporation of air into the finish increases the viscosity of the coat, whilst the changes in shear characteristics and strength that it is possible to accurately control the weight of the coat [23].

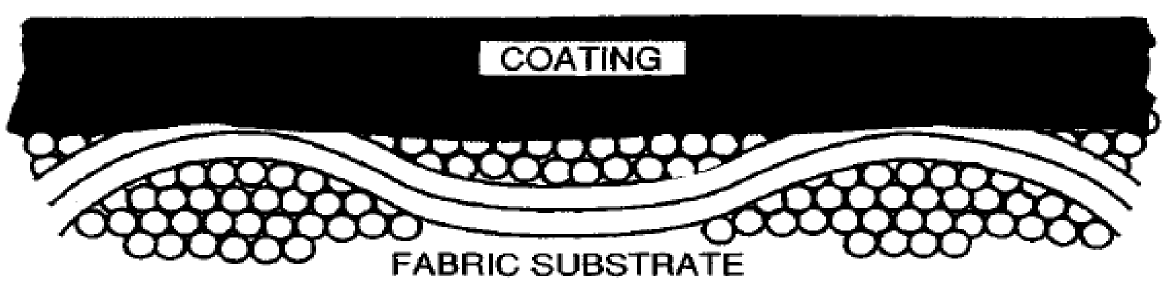


Figure 2: A coat layer on the fabric surface.

2.5 HISTORICAL BACKGROUND

Historians have been able to trace the history of coated textiles for thousands of years. Some believe that fabrics used to mummify bodies in Ancient Egypt could be considered as coated. Early evidence also comes from the South American countries, where the native people used to collect the milky white resins from trees and apply in on the fabric. The rubber latex used to then coagulate in the sunlight allowing the material to become waterproof and elastic. Another type of coat that was used was from natural oils such as linseed and tar. The oils would be repetitively applied onto the textile and left to dry, until the material was waterproof. This method continued into the early 18th century were many English and German manufacturers experimented with different oils onto different textile materials [21].

However, most people believe the starting point in history came in 1823, when Charles Macintosh discovered a method to combine rubber and fabric so that the resultant textile provided adequate protection. Macintosh had found that coal naphtha dissolved in rubber and that by applying the mixture in between material to improve the level of protection. He patented this method in 1823 and became a household name across the world. Despite being bought off, the Macintosh Company still exists working with other leading fashion brands such as Luis Vuitton and Gucci. However, it still is popular in its own right with the company's most famous item being the Macintosh raincoat. Macintosh's product became popular for various different applications besides clothes; however, there were many complaints about the original material. Customers pointed out that the fabrics would give off and unpleasant odour and appearance. It was also noted that the rubber would melt and become sticky when exposed to high temperatures. The vulcanization process in the 1840s, helped to deal with these issues. Vulcanisation refers to a process that crosslinking of rubber with sulphur reactive groups [8]. Further improvements in the industry came from the breakthrough in chemistry which gave rise to new polymeric materials for both yarns and coats. These polymers are essentially the most used finish to be applied in textile industries nowadays. Currently, products such as GORE TEX and Sympatex are leaders in producers' garments that have excellent capabilities in water repellence.

2.6 INTERGRAL ASPECTS IN COATING TEACHNOLOGY

2.6.1 ADHESION

A key factor when coating is to attain strong interlayer bonding between the coat and substate material. Adhesion properties between the materials is related to the interfacial strength between the layers. It is also important to factor in the interaction between the adhesion and other properties such as tear strength. Adhesion is defined as the attraction forces that exist between two materials which are in contact with each other . The strength of the adhesions can be given by the cohesive forces of bulk materials and their interactions between the layers. Generally, the work of adhesion can be given as $Wa = \gamma_1 + \gamma_2 + \gamma_{12}$ for a smooth flat surface; where γ_1 and γ_2 are surface tensions and $\gamma_{12}$is the interfacial tension. A materials ability to adhere is affected by its chemical nature and thus the different types of polymers in the applied coating and their chemical affinities.

When textiles that are comprised of different layers don't have enough affinity between them, their level interfacial adhesion is low. Thus, affecting the longeivity of the material. The interfacial difference of polymer chains can also determine the adhesive propeties that a fabric has. This analysis can be used to determine the level of adhesion between molecules that are in different phases. When there is sufficient interaction and affinity between 2 phases it is possible for polymer molecule to diffuse beyond the interface to form entangled structure with the other phase. When polymeric material is heated, their molecules possesss high mobility which allows for movement of the molecules to penetrate deeper into the other structure, thus having better adhesion. Certain coats may need more time for curing, because the high temperatures allows better adhesion.. The level is therefore also affected by temperatures in application as well as the time allocated for the coating procedure to take place [20].

2.6.2 RHELOGICAL ASPECTS

An integral aspect during coating is the determination of thickness in regards to how much of the polymeric coat needs to be applied onto the material. The thickness of the coat and depth of penetration are key factors in determining the success of the coat for its final use. It is important to match up correct substrates that have a good mechanical adhesion which allows for the polymer to bind with the textile. It must also be such that the coat doesn't seep through the material and be visible on the other side. The rheological properties of the coat are therefore a necessary factor to consider[6].Rheology refers to the resistance of a liquid to flow. It accounts for the flow properties that a liquid has in terms of its velocity and shear rate. Liquids can be then classified to be either Newtonian or non Newtonian based on the relationship between its shear stress and shear rate. Non Newtonian liquids are those whose velocity is not constant however a function is its shear rate. The flow of the liquid coat is determined by the shear rate. It is especially important that in paste coats that the velocity at both high and low shear rates are known. High shear rates could lead to unevenness in the coat distribution whilst low shear rates can affect the yield in the final appearance. Typically, dispersions that have more than half of its content being a plastisol exhibit Newtonian behaviour. They can be psuedoplastic, dilatants or thixotropic depending on the method of formulation. The shear rate also affects the flow behaviour i.e. a paste may have a psuedoplastic behaviour at low shear but dilatancy at a moderate rate [18].

2.7 COATING TECHNIQUES

There are several different methods in which coats can be applied onto textile fabric. The choice of procedure is dependent on several factors. Firstly, it is important to know the rheological properties of the polymer as a thicker paste/foam requires a gap to allow more of the finish to be applied. Secondly, the type of material is also important as it plays a part in ensuring that depth of penetration is correct. A third factor is product end use, as it is common in industry to use specific technique for creation of specific parts. A list of some of the techniques is as follows:

Knife over roller technique: This is probably the most common practice used in production. The doctor blade is placed directly above the roller such that there is very minimal (0.01mm) space between the blade and material. The chemical finish is poured in front of the blade which spreads it out, as evenly as possible. The fabric is run at a predetermined rate between the blade and roller. The resultant coat is highly affected by the speed and viscosity of the paste as well as the knife properties. In industry there are different kinds of knifes available for use depending on the coat and application. The angle and positioning of the blade therefore also impacts the final result. The diagram below illustrates the procedure.

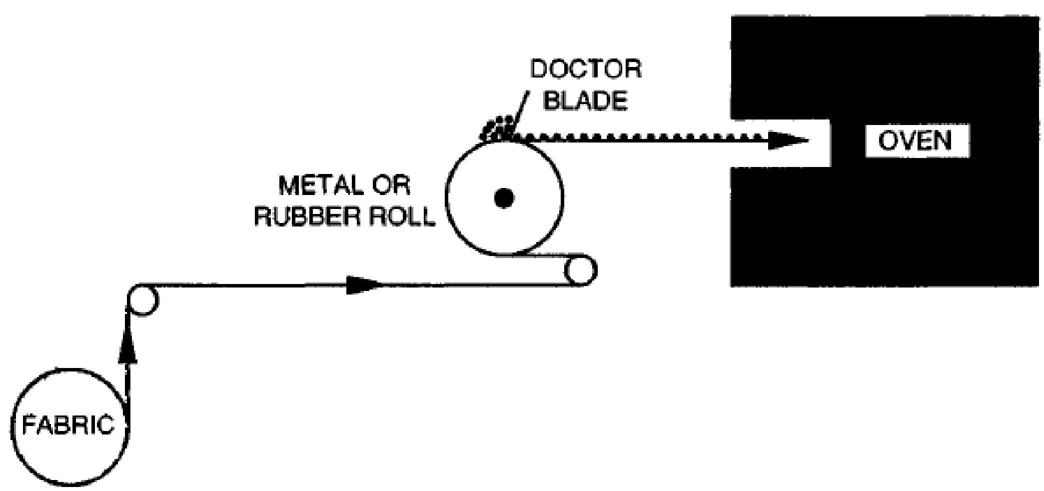


Figure 3: Knife Over Roller System

Air blade technique: This is a method that is similar to the knife on roller but differs in that the blade is set slightly higher from the material. The increased gap allows for finishes with higher viscosity coatings that are heavier to be applied. It can also be used for fabrics that have already been pre-impregnated. The thickness and weight of the coat is controlled by the tension in the fabric. This is illustrated below in Figure 1.7.2.

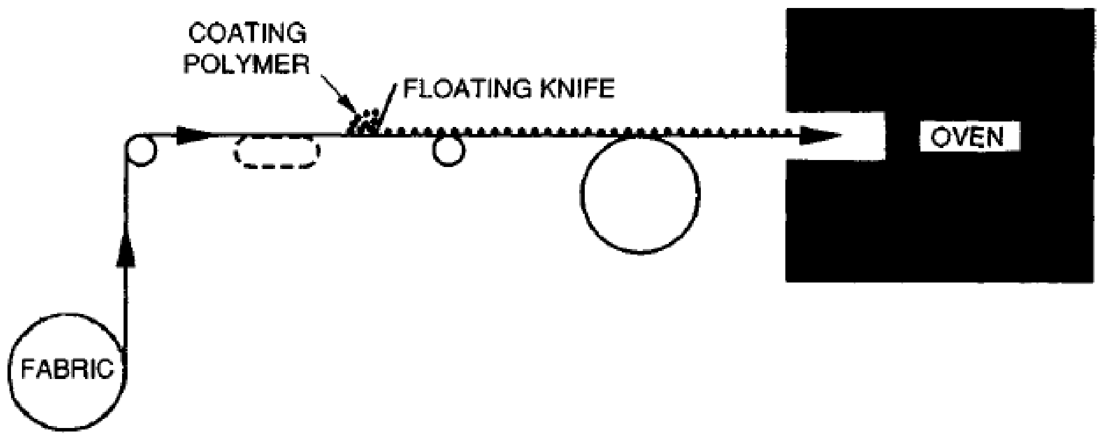


Figure 4: Air Blade Technique

Back coating Technique- in this method the polymeric coat is filled into a trough. The fabric passes onto a gravure roller which has been in contact with the trough. Thus, the back of the material the coat is applied. These are excellent for use of finishes that have low viscosity [] Figure 2.7.3 illustrates the procedure.

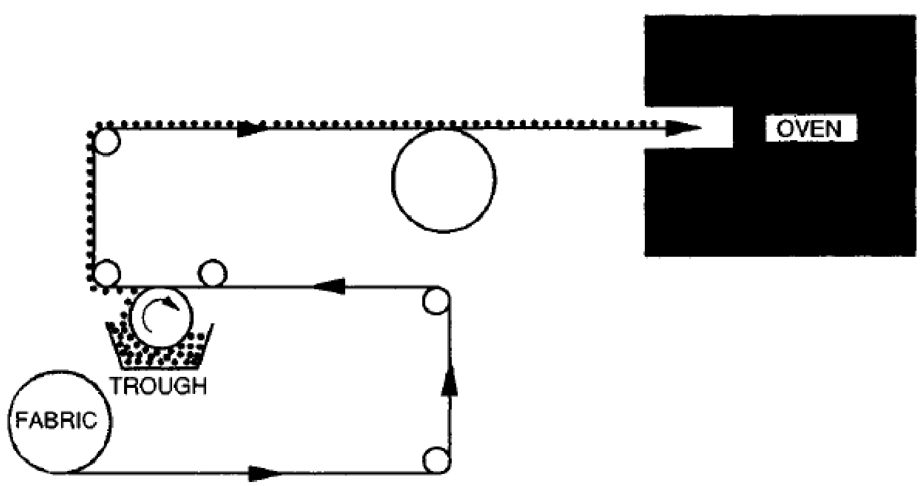


Figure 5: Back Coating Technique

Reverse roll: during this procedure there are two rollers, one moving at a comparably lower speed to the other. The slower roller is able to control the thickness of the coat spread on the surface of the material. This can be done by also adjusting the distance between the two rollers. The other roller is in contact with the textile surface which is being transferred by the main rubber roller. The contact between the two allows for coat to be deposited on fabric surface. This can be seen in Figure 1.7.4 below:

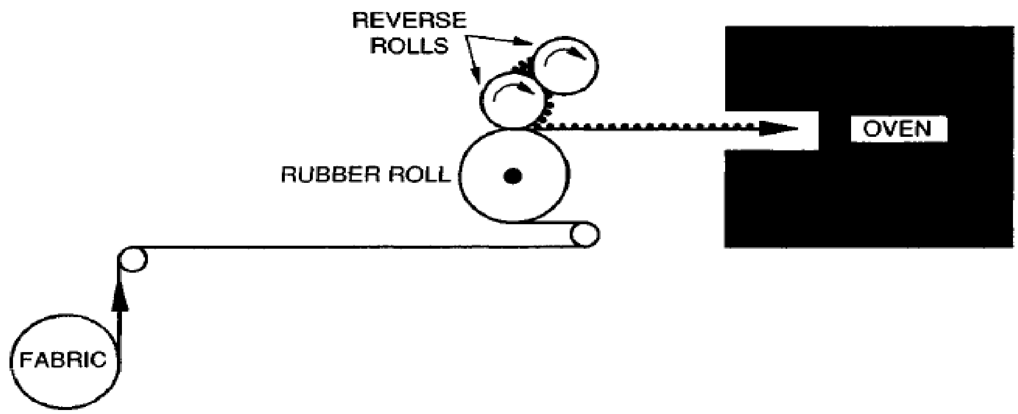


Figure 6: Reverse Roll Coating

Transfer coating: this is a 2 step process that utilizes a doctor blade to apply the coat by a silicone transfer paper in a similar manner described in 1.7.1. The transfer paper is composed of a smooth non tacky film that has the polymeric finish known as a tie-coat applied onto it. The textile is coated with the transfer paper, and dried and cured. Thereafter, the paper is peeled away so that there is a smooth coat remaining on the textile. The mechanism is illustrated below:

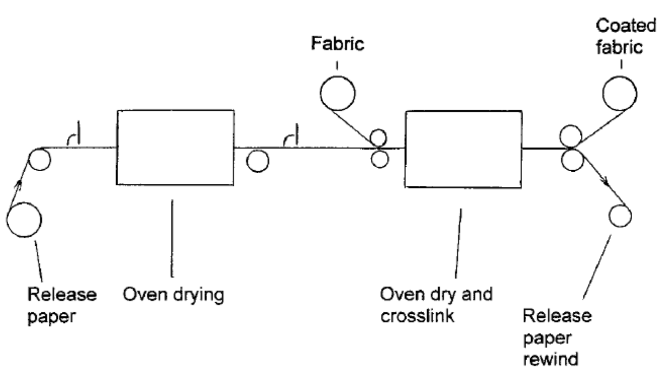


Figure 7: Transfer Coating Mechanism

2.8 CHEMICALS IN COATING

Polymers are essentially the backbone to the textile coating finish. However, these finishes are not just a single polymer, but rather a mixture of different chemical ingredients. Polymers that are used I coating compounds can generally be classified as either elastomers or thermoplastics. In addition to polymers, coating mixtures also include fillers or extenders. These are economical additives to a finishing recipe as they are lower cost to the polymer and don't alter the properties of the coat, but rather enhance them [5]. Each chemical added to the recipe serves a specific function that can either be for the coating mixture (such as to control thickness etc.) or to improve a property for the end use of the coated textile. Common additives are viscosity modifiers to control the rheology of the coat. Reaction modifiers are used to either accelerate or slow down the time for the coat to set. Other additives include flame retardants, ultraviolet absorbers, surface friction modifiers, abrasion resistance enhancers, chemicals to modify the water vapour properties and pigments for color and appearance. Other chemical fillers that are inert are used to provide opacity or reduce the costs of the finish [1].

2.8.1 METHODS OF POLYMERIZATION

All modern day coats are created from polymeric compounds. Polymers are produced via a practice known as polymerization. This is a process in which single structures or monomers are bonded together to create polymeric networks. This reaction between monomers can either be stepwise; which conjugates functional groups in the structure or it can be chain growth which bonds the structures in double or triple chemical bonds [17]. There are four different types of polymerization:

<u>Bulk polymerization</u>: This method is also known as mass polymerization and involves heating of the monomer in a vessel. It doesn't contain a solvent but rather a initiator which reacts with the monomer, to create a solid shaped polymer in the shape of the reactive vessel. The disadvantage of this technique is that it is highly exothermic and requires adequate cooling mechanisms.

Solution polymerization: These are reactions that take place in solvents. They are often used to create the polymers which are in solution form. The solvent aids in the reaction by controlling the distribution of heat.

Emulsion Polymerization: This process creates latex polymers which are stable emulsions. The reaction generally involves the use of water and auxiliary agents such as surfactants or emulsifying agents. The monomers can either be added gradually or all at once at the start of the reaction. It is a very fast reaction that produces very small particles as they are not formed by the monomers but rather in the micelles.

Suspension Polymerization: In this technique the monomers are suspended in water or water based agents and utilizes mechanical agitation techniques to mix the monomers and create droplets.

2.8.2 RUBBERS

Historically the first chemicals in textile coatings were from rubber exuded from trees. Rubber is an amorphous macromolecule at room temperature which in raw form, can deform into a plastic like structure since it has no rigid network structure. The Vulcanization process crosslink's rubbers with sulphur to create elastomers. These elastomers are capable of have large elastic deformations. Different types of rubber products exist. The first is natural rubber which is collected from plants and trees and turned into latex by coagulation. These latex rubbers are composed of 90% rubber hydrocarbons as 1, 4 –polyisoprene and the rest are other resins, proteins and sugars that are removed during coagulation. The rubber tends to have a wide distribution in molecular weight thus making them easier for processing. Vulcanized natural rubber has excellent properties such as high tensile strength, good tear resistance and flexibility at low temperatures and is useful for many applications in industry.

The second type of rubber is a styrene- butadiene rubber. These are copolymers of styrene and butadiene and structure is illustrated below in figure 2.8.2. It is made by emulsion polymerization. The rubbers can be separated into two classes; hot and cold polymerized grades. They have good heat and aging resistance and generally are utilized with natural and other rubbers. The third type is Isoprene-Isobutylene Rubber. These are butyl rubbers that are copolymers of isobutylene which is the majority and a little of isoprene. The isoprene enables the vulcanization by supplying a double bond. The rubber is created by cationic polymerization with methylene chloride with an aluminiumtrichloride catalyst in below zero temperatures. They have excellent resistance against weather conditions and chemicals as well as low gas permeability.

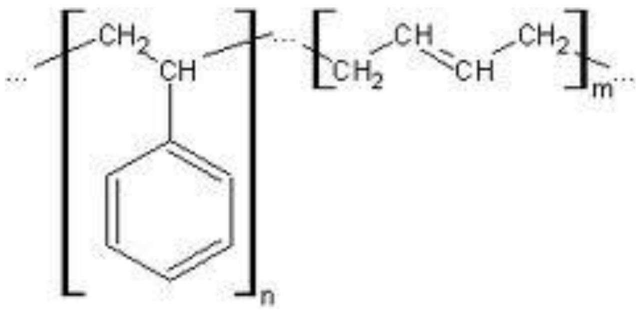


Figure 8: Structure Styrene Butadiene Rubber

The fourth rubber is Polychloroprene Rubber. They are also produced via emulsion polymerization and contains 98% 1, 4 –addition products, whilst the rest are 1, 2 addition products. These rubbers have excellent resilience to oxidization and ozone. The molecular structure contains a Cl atom which gives the rubber good flame resistance as well. The next type is nitrile rubber. This is copolymer of acrylonitrile and butadiene that is produced by emulsion polymerization. They offer high resistance to oils and fats. Silicone rubbers are another type of rubbers. It is created from silicones which are polysiloxanes that have Silicon and oxygen bonds. They are useful because they have excellent stability over a wide temperature range which is a unique property. Therubbers have good chemical resistance and are particularly excellent for water repellence. They have a transparent coat [18].

2.8.3 POLYVINYL CHLORIDE (PVC)

This is a synthetic polymer that is popular in industry as it is cheaper and has a wide range of useful properties. It is able to compound with a variety of additives and is easy to process. It is composed of repetitive units that are linked mostly head to tail and has a linear structure. Figure 2.8.3 below depicts a single PVC unit. It can be produced by several different polymerization techniques such as emulsion, solution and most commonly suspension. However, for surface coatings it is created by the solution process. In production the PVC resins are chosen based on different characteristics such as molecular weight, bulk density, plasticizer absorption, electrical conductivity etc. To create specific qualities in the PVC coats, they are compounded with additives. The most common ones are plasticizers, heat stabilizers, fillers, lubricants, colorants and flame retardants. Plasticizers help create polymers that have more softness and flexibility. They give a lower glass temperature and softening temperature and have increased impact resistance. Heat stabilizers are used because PVC alone can degrade during production. Fillers are added because they are cost effective and improve the process ability of PVC. Typical fillers are calcium carbonate, silicates and barites. Lubricants aid in controlling the rate of processing and are ideal for stabilizing as well. Colorant additives are both inorganic and organic pigments that bring good heat resistance as well as light stability to the final product. PVC is inherently flame retardant but as it contains a chlorine atom in its molecular structure. However, some plasticizers alter this capability, thus making it necessary to add more chlorine containing compounds such as chlorinated paraffin and phosphate esters to increase its protective ability [18].

—CH 2 — CH

Cl

Figure 9: Single Unit Of PVC

2.8.4 POLYUTHERANES (PU)

This is a common polymer employed in hydrophobic finishing as it provides excellent resistivity (water and flame) properties. These polymers are not directly utheranes but rather they are a derivative of a reaction of polyester or polyether's with di – or poly-isocyanates, which results in complex structures which have utherane linkages. They are segmented prepolymers that contain linear polyester or polyether that gets extensive chain length by utherane linkages [21]. The prepolymer molecule can be further extended and crosslinked with an isocyanate. The polymer is prepared by using an isocyanate compound which is created by condensing primary amines with phosgene. This reacts with an amino or hydroxyl groups. There are two ways in which PU are prepared. One-shot process:

during this process the polymer is created during one step. The polyol, diisocyanate, chain extender and catalyst are mixed in together at the same time, in an exothermic reaction. The second method is pre polymer process which is a 2 stage production. During the first stage, diisolcyanate and polyol are reacted together to form a so called prepolymer. This prepolymer can then be either NCO or OH terminated. It is then reacted with a chain extender with a polyfunctional alcohol or amine to create the final polymer.

In terms of coatings, they are generally solution based and therefore can be classified either one or two component system. In one component systems there are two main types. The first type is a reactive system which has low molecular weight prepolymers and terminal isocynate group. These are then dissolved in low polarity solvents and have to be cured after the coat has been applied. Water is used to be a chain extender and cross linking agent. The second system is a completely reacted one-component system. This method has a high molecular weight theromoplasticPUelatomer that has been completely reacted, and then dissolved into a high polar solvent. The coats that are produced from this method are physically dried and generally don't require any subsequent curing. In the two components system the isocynate-terminated prepolymer or polyfunctionalisocynates are reacted with polyhydroxy compounds. The polyisocynate is mixed with the polyhydrxy compound before the coat is applied and is in solution form typically. These types of PU coatings offer good dry cleanabilitysince it contains no plasticizers. They have flexibility at lower temperature and soft handle. They have high tensile ability; tear strength and abrasion resistance [18].

n (NCO-R-NCO) + n (HO-R-OH)→

OCN-(-R-NH-C-O-R-O-C-NH-)$_{n-1}$ -R-NH-C-O-R-OH
||||||
OOO

Figure 10: Chemical Structure of Utherane

2.8.5 ACRYLIC POLYMERS

These are monomers that are esters of acrylic acid and methacrylic acid. The ester can be seen below... the acrylic polymers tend to be soft as opposed to the methacrylate polymer which are hard and brittle. They are produce via different methods of polymerization such as bulk, suspension, emulsion and solutions with the latter two being customary in coating formation [18].

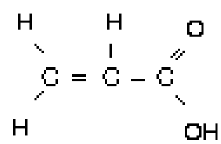


Figure 11: Chemical Structure of Acrylic Acid

2.8.6 FLOURO CHEMICAL FINISHES:

These chemical finishes are aqueous dispersions of fluorinated polymers which are composed of high molecular weight acrylate polymers. These polymers are synthesized by the reaction of an acrylate monomer that has a fluorinated carbon chain along with other monomers. This fluorocarbon chain is bound to polymer backbone, orients perpendicular to the treated substrates and provides low surface energy barrier to the water agents. Their hydrocarbon backbone allows for the molecule strongly absorb and possibly be covalently bonded to a treated surface. It is compatible with other chemical agents such as softeners and resins are generally non deleterious to the aesthetics of the final material. Most of the chemical finishes that contain flourochemicals originate from two manufacturing processes: electrochemical fluorination (ECF) and telomerisation [3].

Fluorinated coatings provide optimum performance in terms of hydro and oleophibic proopeties without impairing the textiles air and vapour pearmeability. However, they are not sufficiet stability during use. To improve durability – a new perfluoroalkyl containg multi epoxy componds (PFME). It contains both a perflouroalakyl chains nd multicrosslinking groups. Cotton fabrics treated with PFME by pad dry cure method should be durable [19]. In recent years emphasis has been placed on the potential hazards of using these chemicals in industry. Chemicals have been targeted for the toxicity effects mainly due to the presence of perflourooctanyl sulfonate(PFOS) and other perflorocarbolylates. The 3M company has terminated the production by the ECF method due to PFOS and other perflourosolfonyl alkyl presence. Perflourooctanoic acid as well as been shut down. The OECD has classified these chemcials as being persistant and bioaccumulative and toxic(PBT). The chemical has also been seen as hazardous for humans [3].

2.8.7 OTHER FINISHING AGENTS

Numerous other finishes are available on the market taht focus on water repellency such as:

Wax based reppelenst: these are generally composed of 20-25% parafin and 5-10% zirconium alinium based salts. It is applied via a pad-dry process.

Resin based repellents: thses are products of condensation of fatty compounds (acids, amides or amines). With metholyated Melamins. Paraffin wax may also be incorporated. These are applied by a pad, dry cure method.Silicon repellents: Aqueous solutions of polysiloxane (DMPS) and modified derivatives emulsifiers, hydrotropic agents and water. These are typically applied by the pad –dry cure method [9].

2.9 GENERAL PROPERTIES OF COATED TEXTILES

The physical properties of a coated textile material comes from the inherent properties in the original fabric substrate and the coating process in terms of the chemiacl formula, the technique used and processing during and after applicatoin [19]. The table below shows which factor affects a specific property.

Propeties	Substrate	Coating technique/processing	Recipe
Tensile Strength	●	●	
Dimensional Stability	●	●	
Long-time properties	●	●	●
Coating Adhesion	●	●	●
Tear Strength	●	●	●
Bending Resistance	●		●
Chemical Resistance	●		●
Weather resistance	●		●
Burning Behaviour	●		●
Abrasion Resistance			●

Table 2.9 Factors that affect the coating propeties.

2.10 END USES OF HYDROPHIC COATED TEXTILES

2.10.1 ACTIVE SPORTSWEAR

The sportswear industry is heavily reliant on innovations in the textiles manufacturing as it can produce new items that can help improve athletes performances. Beyond clothing production, textiles are used for producing equipment such as trampolines, camping tents, bags, biking equipmentsetc as well as specialized footwear for football and athletic players. The sportswear industry as benefitted immensely from breakthroughs in textile sciences with the ability to create high functional products designed for the specific sport. In designing sportswear, fibrous materials are chosen based on their properties especially in terms of strength and performance. Polyester is the most popular choice in sportswear materials, but other synthetic fibres such as polyamide, polypropylene, acrylates and elastane are common as well. Natural fibers are less used as it is they tend to absorb moisture more easily

A vital aspect in garment design is the concept of comfort in clothing. Comfort can be defined as physiological, physical and psychological comfort that a user attains whilst wearing the clothes. Psychological comfort refers to the fashion sense, colour, look and design that a wearer has about a particular item of clothing. Physical comfort is the comfort in terms of the five senses of sight, smell, taste, hear and touch. In textiles the sense of touch, sight and perhaps smell are they most important. Physiological comfort is the sensations created that are attached to the neural centres in our brains such as the skin irritations like itchiness and prickliness as well as the thermal comfort. The thermal comfort is significant in clothing production. The internal human body temperature is 38^{o}C and the skin temperature varies to around a few degrees below. A human needs to maintain this constant temperature to remain healthy thus, it becomes important that the clothes worn protects and enable this. Clothes must be able to keep a person warm enough to not have their body temperature fall to low during cold conditions but at the same time be able to not over heat the user and vice versa.

Thermal comfort fabrics need to consider these factors in design. During extreme weather conditions such as rain or snow, the fabrics must be water proofed so that the user doesn’t get to cold or wet for the user. This is particularly important for countries that experience very cold temperatures and snowfall. During recreational activities a person tends to produce sweat. This can cause the garment worn to become damp. Wetted materials make the garment to gain extra mass resulting in the cloth collapsing on user's body surface. This increases their feeling of discomfit by creating a cold, clammy sensation for the consumer. The longer the garments take to dry is also important, as being exposed to the cold feeling for too long can cause the person to become ill. Thus, the drying time must also be factored in for comfort in sports clothing. Design should also consider that different parts of the body produce different amounts of sweat [14].

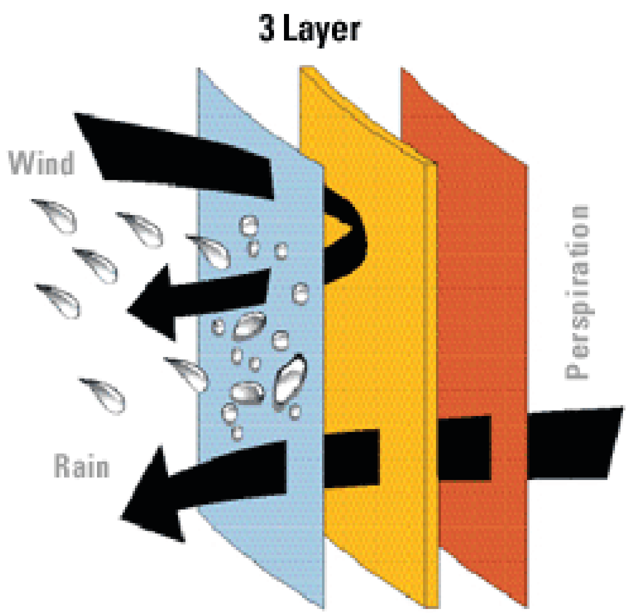


Figure 12: Multilayer Clothing System for protective clothing

Traditonal mode of outdoor wear is a multilayering system comprising of an internal wicking layer a middle insulation layer and on the outside there is an extrenal waterproof layer (usually known as a hard shell). This is illustrated in the figure above. The hard shell can trap body heat and persipartion. However this can be possibly problematic as hard shells are sometimes not brethable enough, creating high levels of discomfort. This leads to most hard shell prodcuts ineffective for high performance active sports. The alternative is Soft shell which has revolutionized the industry by being more strecthable, having a tigheter fit and better mobility. Incorporating the inner layer also ensures the temperature gradient exerted across the outer waterproof breathable layer is reasonably realistic.

2.10.2 AUTOMOBILES

The automotive industry is highly reliant on the textiles manufacturing industry as technical textiles are utilized in various different car parts. The most common of these are car seats, seat belts, door casings and airbags. Typical textiles for seat covers are genuine and artificial leather as well as polymeric materials. Performance tests for these materials are done to ensure their ability to withstand long term effects of UV and abrasion. It is also essential that it can maintain good heat stability as climatic conditions in cars can be varied across a wide temperature range, from extremely hot weather to cold, snowy days. Thus, breathability is also a key factor especially for seat coverings. General coat applications for these products are from back coatings with polyutherane or acrylic resins which aid in abrasion resistance. Froth coats also improve this property, but are applied on the fabric face. Fabrics that are used in the door panels are often coated with PVC latex so as to enable them to weld with the other surrounding materials easily. Airbags are a safety feature is most modern day cars and protects the person from serious injury by cushioning their impact during an accident. Nylon 6 and Nylon 6.6 are the first used coats on airbags but silicone treatments via an air blade technique are also used. Coated airbags must be produced such that theycan be folded and kept for 10 years without any damage or the coats losing efficiency by sticking together. Coated textiles are also used to create coverings for convertible cars. Polyester, nylon, PVC coated cotton and rubberised cotton are commonly used in production, although cotton tends to have less desirable performance. The construction of this part is important as it requires many different levels of protection. It must be waterproof in times of rain and snow as well as resistant to UV and microrganisms. It should also be easily washable and resist dirt, traffic fumes and chemicals from cleaning, which is achieved by applying a fluorocarbon coat [8].

2.10.3 MARINE APPLICATIONS

Textiles are used to create various different components in boating industry, from inflammable crafts to flotation devices and other safety equipment as well as sails for ships. Inflatable boats have become a popular choice for many functional purposes as opposed to rigid crafts. They are used for life boats and rescue craft, as well as freight carrying vessels and also having a number of military applications. Their benefit is that they can be inflated and deflated according to when it is necessary for usage, making storage and transportation easier. These materials are constructed such that they must be completely impervious to water whilst marinating to carry a high load. Polymeric coats used are butyl rubber, natural rubber, polyurethane and polychloroprene. Survival equipment such as life jackets, life rafts and escape chutes is generally made from woven nylon coated with polyurethane or a synthetic rubber. However, PVC is not a recommended as it is prone to cause fires via toxic gases. Sails are also typically either nylon or polyester woven materials that undergo resin finishes such as acrylic and polyutherane. They need to be water resistant and prevent the microorganisms and mildew [4].

2.10.4 BUILDING APPLICATIONS

These include tents, and marquees for outdoor exhibitions, sports arenas etc. The benefits of using coated textiles for buildings are that they are easy to construct and can be deconstructed. It is faster to put up and take down which is very useful for emergencies. They are cost effective and the weight of the coated fabric has been valued as about one-thirteenth of a similar sized bricks and mortar structure. The coated textile used must be extremely strong and withstand harsh elements such as heavy rains, snow and winds. It should also be durable enough so as to not decolorize and not degrade to UV light. They should also resist the effects of microbes, insects and rotting. General materials used for construction are PVC as a ground sheet and a rubber coating on nylon or polyester [8].

2.10.5 MEDICAL APPLICATIONS

It is of the utmost importance that surgeons, nurses and doctors are completely protected in their line of work. Protective garments (often called scrubs) are essential in preventing disease and pathogens from spreading, especially in the case of those that can be transmitted via blood such as AIDS. Coated textiles are utilized as they can provide resistance to blood and other liquids as well as microbes whilst allowing the user to be comfortable. Fluorocarbon treatments for liquid repellency are typically used whilst in some cases, coatings with GORE-TEX have also be applied. Coat finishes also depends on the institution, as some use disposable garments whilst in Europe and the UK, clothes are reusable. These attires have to coat such that they are able to withstand multiple washes at high temperatures and sterilization. Mattress covers coated from Polyurethane, transfer coated, raised knitted nylon fabrics are used as for incontinent patients. The material must be washable and capable of withstanding repeated sterilizing and disinfectant treatments and still being water resistant [8].

2.10.6 MILITARY APPLICATIONS

Military garments are produced to be able to withstand high performance tests. They often called known as foul weather clothes, as they are worn during extreme weather conditions. The clothes must prevent the soldier from getting to wet or cold, and be able to provide comfort over prolonged periods of time. As it is too expensive to kit every soldier with Gore-Tex, it is used merely by specialist forces. The design of the garment is critical as it must provide each individual with adequate properties but also consider other factors such as the rustling noise that can be heard when the clothes made from coated and laminated fabric move can be a security issue in stealth operations. Foul weather garments are generally produced from material printed with a ‘disruptive’ pattern to reduce visibility in the field aka camouflage.

2.10.7 HOUSEHOLD PRODUCTS

Waterproof coated textiles can be found in many different materials in a household. Modern day carpets are designed such that they can resist the effects of dirt and liquids by making use of synthetic fibers that have a back coating. The most widely used application is in shower curtains and other bathroom applications. Shower curtains are designed to prevent water from falling onto the bathroom floor and need to be completely waterproof. They are also required to have a good drape and not be too stiff. Besides a waterproof coat, the shower curtains are also finished with anti-microbial finishes as they are susceptible to mildew from the action of the soap and water. However, these finishes are not always 100% effective and need to be washed on a continual basis. Soap residues attach themselves to the fabric and the mildew grows on the soap. Shower curtains from coated fabric, generally 100% woven polyester, are considered to be more up market than PVC sheet which does not drape as well, invariably has plasticizer odours and which could eventually stiffen and crack. The handle of these curtains must be crisp but not stiff. Their performance requirements are ‘rain resistant’ standard as opposed to than waterproof level. In manufacturing it is possible that clients may specify their performance output level, meaning that some would be satisfied with only a spray rating whilst others would require testing using the Bundesmann or WIRA apparatus.

2.11 FUTURE TRENDS IN COATING TECHNOLOGY

Continuous research and development in the textiles sciences means that there are always new inventions and/ or novel techniques are found for the production process. Likewise in coating industry improvements on existing technologies as well as new innovations are being developed. This is done also so that the end products can be more efficient in performance. Consumer demand for trendier items have put pressure on manufacturers to create new technologies as well has faster turnaround times for production. Companies continually research ways in which existing technologies can be improved so as to have more efficient and faster turnaround.

2.11.1 YARNS

Developments in creating yarns that have improved properties that can be advantageous to the end product. This could result in woven materials that have specific specialized characteristics inherently added into their structure. The benefit of this is that the material produced would not require excessive chemical finishes in manufacturing. This can lead to a product that is more economical for the producer as well as the consumer. New products include yarns such as very high strength or high modulus polyethylene Spectra or polyester that can be used in composites and constructional applications. The Gore-Tex Company has developed new yarns from PTFE fibers that have 50% more tensile strength as compared to the current yarns on the market. The applications of such yarns can be for many building applications. If the textiles created with these yarns are coated with the same polymer, those materials are more easily disposable and allow for better recycling.

2.11.2 MANUFACTURING TECHNIQUES

Innovations in coatings technology means that companies can benefit from new techniques in application. For the automotive industry two new methods have arisen. A ‘foam-in-place' method which can be used to create car head rests. This technique allows for a chemical solution that is filled onto a bag that already has the cover sewn onto it. The chemicals in the liquid react to form polyutherane foam which has a high density and low porosity. The other technique is a one shot manufacturing process that utilizes a film laminate is placed into a mould and the polymeric solution can be directly injected into it. The laminate prevents the polymeric solutions from seeping out and affecting the surface of the fabric. This method is particularly useful for rigid structures such as door casings. Another innovation in manufacturing is the use of different welding techniques to improve the seam quality in garment production. Seams are generally seen as the weakest points in clothing, particularly in specialized coated materials, such as waterproof textiles as it is difficult to adequately coat them and have good bending properties. Welding techniques improve the ability for seams to be created without holes especially from new methods such as laser welding [8].

2.11.3 SOL-GEL APPLICATIONS

A sol-gel can be descried as colloidal solutions that contain solids in a liquid medium or a sol that is used to create a macromolecular network known as a gel. It is possible to use this technique to create polymeric solutions (typically containing silica atoms in their structures) that can be used for coatings as well as porous films. The porosity and surface properties of such films can be also controlled thus it can effectively be used to produce materials that are both waterproof and breathable [2]. In order to attain hydrophobic properties in textiles, they make use of Nano particles to change the surface roughness properties. This affects the wettability of a textile, and decreases the contact angle to have improved resistance to water. Sol-gel processing can allow for Nano-particles that contain chemicals that are resistant to water such as fluoro compounds or silica gels. Since it is possible to develop different kinds of Nano-particles, this treatment can also be used to create different levels of hydrophobicity. This means that manufacturers using this technique are able to produce textiles according to client's requests or industry standards as accurately as possible [15].

2.11.4 PLASMA TREATMENTS

Plasmas can be described as a fourth state. It is essentially ionized gas that contains particles. This technique is more advantageous than traditional coatings as they are more economically and ecologically efficient. This is due to the plasma treatments not being heavily dependent on chemicals and water in application. This is especially beneficial in reducing the effluents created in manufacturing as well as the number of pollutants created. These treatments can be considered as an environmentally benign technology. Plasmas treatments are favorable in coatings technology as they can be used to enhance the adhesion properties of a substrates surface. This is can be done by adding functional groups on the surface that can provide affinity to a coating finish. It allows for improved bonding between the substrates and for coats that need to be fixated, it aids in allowing better depth of penetration.

These treatments can be applied on all fiber types and can either increase or decrease the wettability of the fabric surface. This is because it introduced new functional groups into existing structures. For hydrophobicity effects, the auxiliary functional groups remove and replace the existing hydrophilic groups. This can be done by the use of a gas that doesn’t deposit the group on the surface but rather exchange the hydrophilic group with a typical hydrophobic one such a fluorine group in a process known as grafting. Another method of application is by coating the material by immersing it in a solution that comprises of a hydrophobic prepolymer. Thereafter the textile is plasma treated to allow the prepolymer to be grafted onto the textile surface. The technique with the highest possible effect on hydrophobicity is deposition. This method deposits the polymeric compound on the textile surface whilst it is in a plasma reactor. The deposition can take place either in a 1 or 2 step process. The 1 step process is direct deposition when the plasma is ignited known as plasma polymerization. The 2 step process involves the creation f free radicals in inert plasma and thereafter, having the monomers being grafted [16].

2.11.5 SMART RESPONSIVE TEMPERATURE COATING

A novel invention is the use of smart responsive breathable coatings for textiles. Traditional coating applications are passive and don't respond or modify when the external environmental conditions change. Stimuli sensitive polymers (SSP) can be used to construct a breathable fabric that can be temperature dependent. These are called smart polymers that undergo reversible alterations from one state to another as a responsive property to temperature changes. They are commonly in hydrogel form in which they can display a reversible change from hydrophilic to hydrophobic form in a transition temperature range. This is due the fact that SSP's have both hydrophilic and hydrophobic groups in their structure. An example of this type of polymer is poly(N-isopropylacrylate) (PNIPAm) which is currently being used as a smart breathable coat in hydrogel form. It has a hydrophobic backbone and a pendent group which a hydrophilic amide moiety and a hydrophobic isopropyl moiety. The chain structure can be either extended or collapsed depending on which property (hydrophobic or hydrophilic) is dominant. It has a transition temperature of 33^{o}C, below which the polymer gel begins to absorb water and starts swelling. A conformational change takes place from a state of extended to coiled chains when temperature reaches lower critical solution (LCST).

In most SSP's the transition temperature of the polymer can be varied by using additives, designing monomer structures and copolymerization. Typically these polymers are used in hydrogel form because they are soluble in water at temperature below their LCST. However, the problem with using them in gel form is that there is a slow response at transition and can have weak mechanical properties. Thus, it is unable to be applied onto materials with thin dimensions. This problem can be overcome by converting the linear copolymers into the desired shape making use of cross linkers that won't affect the stimuli sensitive response in the material. The resultant polymers have fast transitions and high functional efficiencies. This new coat application can be ideally used for sportswear [13].

3 EXPERIMENTAL PROCEDURE

3.1 AIM

The aim of this research is to determine the level hydrophobicity in cotton samples. The experiment was done to determine:

a) The effect of applying a polymeric coat on cotton samples, each with a different level of porosity in terms of their water repellence and breathability.

b) The effect of using two different polymeric coats; a paste and a foam coat in terms of their efficiency in attaining waterproof and breathable fabrics.

There are two main aspects covered during the experiment procedure. The first step was the materials selection and application of appropriate finishes. The second step dealt with the textile testing of the finished materials to analyse the efficacy of the coated samples.

3.2 COATING METHOD AND MATERIALS

3.2.1 COTTON SAMPLES

The initial process was to sort through the cotton samples. Seven different samples, each with a different porosity and thickness were used. The samples were each cut into 6 pieces, each with dimensions approximately 100*45cm. Each sample was categorised according to the character and numbered appropriately, thus forming six sets of samples. The table below lists the names of the samples and their properties in terms of the porosity values, the areal density per metre and the number of warp and weft yarns found in one metre squared of textile material.

MATERIAL	POROSITY[%]	AREAL DENSITY g/m^2	WARP NUMBER (m^2)	WEFT NUMBER (m^2)
Polar	0.01	210	410	210
Platno	2.17	140	260	210
Kepr	0.005	215	320	190
Karel	0.04	320	320	140
Mitkal	10.27	115	250	200
Zuzana	6.82	140	270	190
Sara	5.14	140	250	200

3.2.2 CHEMICALS

Pre-impregnation: 30g/l Texafob LJ100 – Fluorocarbon

0.5ml/l CH_3COOH – Acetic acid

Coat finish: 50 g/l Texafob G: Acrylic/Polyutherane

Foam Finish: Myflam 8100 XPE: Acrylic/Polyutherane

Post treatment: 50g/l Texafob LJ 100- Fluorocarbon

10g/l Texapret TP10- Crosslinking agent

1ml/l CH_3COOH- Acetic acid

3.2.2.1 Chemical Properties

TEXAFOB LJ: This is a Fluorocarbon compound suitable for all types of materials, natural synthetic and blends.

TEXAPRET TP: this is a crosslinking extender that is suitable for fluorocarbon compounds. It ensures and enables more efficient hydrophobic effect and improves the fabric handle. It is formaldehyde free and non-ionic.

MYFLAM: This is a water based coating system typically created from either acrylic or polyutherane emulsions. It can be used in creating textiles that have multi barrier protections such as water repellence as well as flame retardance.

TEXAFOB G: This is a water based acrylic/polyutherane (80/20) chemical finish that is suitable for all fiber types, natural, and synthetic and blended. It is miscible in water and has a pH of 10, making it very alkaline, and has a slight ammonia odour.

3.2.3 MACHINE:

The machine utilized for all function; pre-treatment, coat, foam and post treatment was the Werner-Mathis AG (CH-8155) that has a Foulard (dryer). Different blades where attached based on the required treatment. The foam was created using a MONDOMIX VS15 automatic mixer which mixes the foam according to the desired parameters such as thickness via a control panel. It mixes and can pump the chemical directly onto industrial machines.

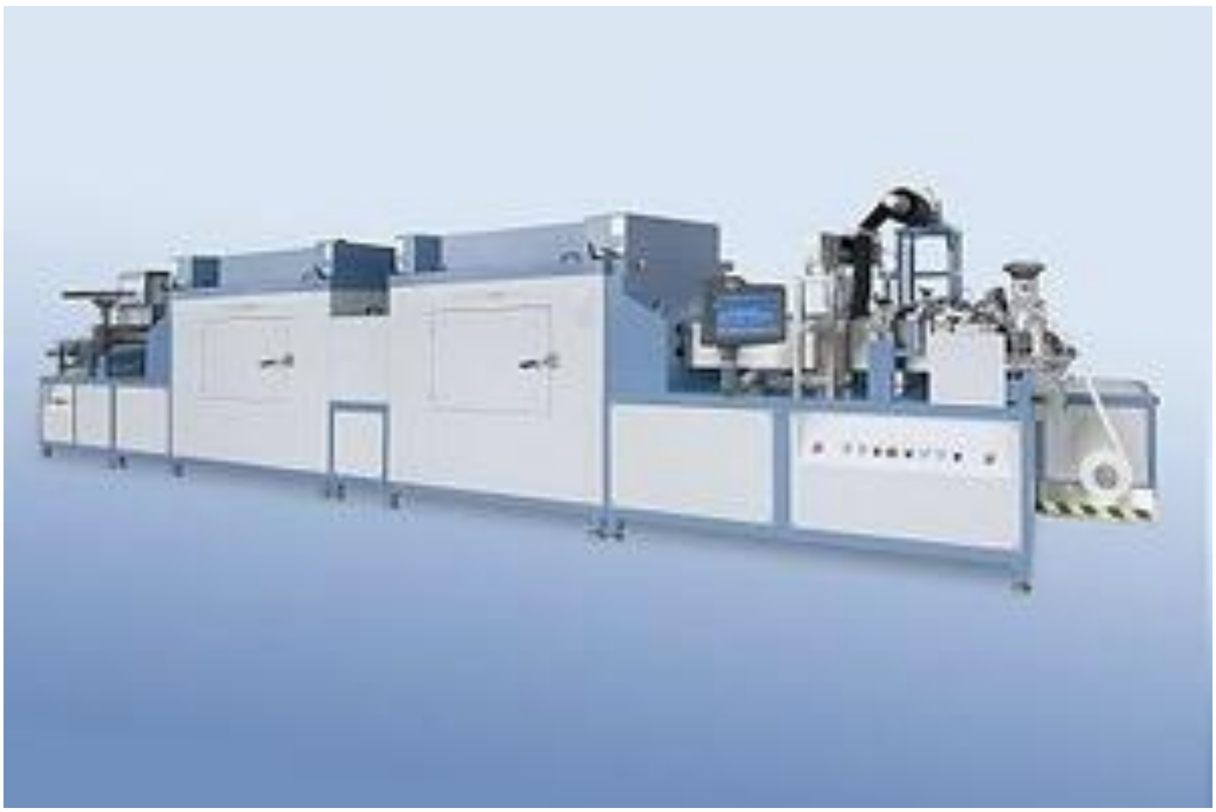


Figure 13: The Werner Mathis Machine

3.2.4 METHOD

The first step was to take a set from the samples and sew them together. This was to allow for a continuous flow when the materials were run through the machine which enhances the equality of the coated effect on the material. Additional materials were also sewn at the start and end of the compiled sets. Their function is to run at the start to allow initial straightening and ensuring the materials receive an even flow of coat. At the end the additional material allows for the finish to run onto before being scraped up, which ensures that all the essential material in between is adequately covered.

The sewn materials are placed onto a metal roller. They are initially run through the machine to allow uniformity and remove any wrinkles etc. Thereafter, this first set is run again through the machine with the pre-impregnation chemicals according to the recipe was applied. It was run for 2 minutes at 120^{o}C, drying only, and no curing was done. The next step was to remove the additional material at the end and attached another two sets of samples, with the excess material reattached at the new end point. All of these combined materials were run though the machine and the polymeric coat was applied. A doctor blade was used with adjustable weights to control the depth of the flow. The materials were run for 3 minutes at 120^{o}C and thereafter cured at 180^{o}C for 1 minute.

The next stage of the experiment was to conduct the foam finish. Two sets of materials were sewn tighter; however they were separated according to the weight. Heavier materials from each set were sewn and rolled onto one roller and lighter materials onto another. Each roller also had excess materials sewn in at the start and end of the sets. The materials were initially run through the machine with water only being applied to allow creases to be ironed out and proper alignment on the roller. The foam was then applied via an air blade technique with a space between the blade and material being about 0.6-0.7mm apart. They were run at 110^{o}C for 3 minutes and cured at 180^{o}C for 2 minutes. The sets where then removed and appropriately sewn back tighter. The final step was to take a paste coated only set and foam coated set and give them a post treatment. They were also run though for 3 minutes at 110^{o}C and cured at 180^{o}C for 1 minute.

3.3 TESTING

The second part of the experimental process dealt with the testing of the properties so verify the effectiveness of the applied finishes for desired characteristics. Testing is an integral part of the textile manufacturing process because it gives a clear indication of the performance of the applied finish. Various different tests can be done, each to test the different properties that fabric may possess. In industry it is incorporated as a company's quality control measures.

3.3.1 SPRAY TEST

Figure 14: Spray test apparatus

This is a test to determine the resistance that a fabric, in particular, those that have been treated for water repellence would have against a continuous flow of water. Water is released onto the material and thereafter it is checked for amount of droplets remaining on the surface or pass through the material. Generally, the fewer droplets on the surface the better resistance the textile possesses. This is because in fabrics that have no or a poor coating, the fabrics will become heavy and causes a significant heat loss. The standard equipment with four basic parts; a metal hoop to attach the sample, a funnel with a shower like head that controls and sprays the water onto the sample, a long metal frame with supports both funnel and hoop in correct positions and finally a tray at the bottom to collect the excess water. The procedure is as follows:

The first step is to condition the samples for at least 24 hours in standard atmospheric conditions (22^{o}C, 65% Relative humidity). The sample is clamped onto the metal hoop such that it is held with the coated side up and the material is as smooth and wrinkle free. This is important as wrinkles may capture water droplets and the exposure would be longer causing erroneous results. Subsequently, 250ml of distilled water is dispensed via the funnel at the top and sprayed onto the sample for about 25 – 30 seconds. The metal hoop is then detached and the back of the sample is checked to see if water has penetrated through. It is then necessary to remove any excess droplets this is done by turning the hoop face side down, holding the an edge face side down and tapping the opposite edge lightly. Rotate the hope 180^{o}C and tap again. Finally, the sample (on coated side) must be compared against the photographic ratings standard and grade it accordingly. The grades are ranked from 1-5, with 1 being the worst and 5 the best.

1 – The full surface of the sample is wetted

2 – Wetting occurred in most places on the sample

3 – Wetting occurred in a few places on the sample

4 - Droplets occur

5 – No surface wetting, no droplets occur on sample

3.3.2 HYDROSTATIC HEAD TEST

Figure 15: Hydrostatic Head test machine

This test is conducted to determine the resistance of textiles to water penetration. The samples are tested with a column of water, in which the pressure gradually rises until at least 3 water drops forms unto the fabric. The testing machine has an electronically controlled pump that creates an internal pressure in the water tank. The sample is clamped onto a test head that is linked to the tank. The sample has to be fixed onto the head as tightly and smoothly as possible. Once the sample is in place, the test can be done where the pressure is automatically controlled. The pressure is gradually increased until water penetrates the fabric in at least three spots. The pressure reading at the third spot is the one that is used for analyses. The pressure is released and the next sample can be put in place.

3.3.3 AIR PERMEABILITY TEST

Figure 16: Air Permeability test machine

This test measures the rate of air flow through the sample material under a predetermined air pressure. Air is pumped through the material until the specific pressure reading is obtained; the corresponding value in mm.sec is obtained as the rate. It is necessary to take a number of readings (generally 10 readings) from each sample, using different spots/positions for each evaluation. This is so that the measurements can be averaged to get a better standard for the materials as opposed to just one result which could be erroneous. The apparatus has a clamping mechanism for the test samples and an external pressure gauge and a manometer which is glass tubes that contain a rubber ball. Before the sample is placed into the machine, both of the valves need to be closed. Once clamped, the vacuum pump is turned on by lightly pressing on the foot pump. Afterwards, valve C can be slowly turned on and the pressure gauge must be checked. If the rubber float doesn’t move or moves to the top, it is necessary to switch to another valve, but ensuring that the first valve is switched off completely. The measurement is taken when the pressure is at a predetermined rate, in this experiment that was 100Pa. When the gauge reads at 100Pa, the corresponding value where the float is at that moment is the final result. Thereafter, the valves must be switched off and pressure released off the pump, ensuring that the meter is back to zero before starting with the next sample.

3.3.4 BREATHABILITY

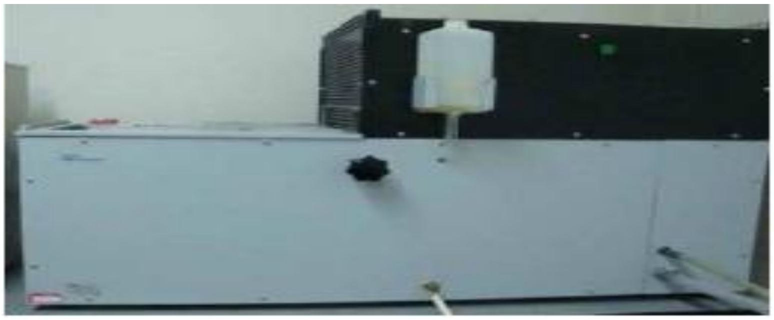


Figure 17: Sweating Guard Hot Plate Machine

This test can be done by different devices which simulates a heating and moisture mechanism that is similar to the way human bodies do. In this regard it can provide information on the breathability properties that a material possesses. In these experiment two tests was conducted, one using all the materials samples on a standard permeability tester with steam according to the standard CSEN 15496. The second test was run for two sample sets in the Sweating Guard Hot Plate machine. This machine can be utilized for testing two key thermal resistance properties, heat and moisture transfer. In these experiments, the apparatus was only used to detect the water vapour permeability. The machinery consists of a measuring unit, temperature controller and water supply unit. The measuring unit is where the samples are placed. Each sample is measured to be 28*28cm. There are 2 different heaters in the machine, a guard heater which surrounds the sample, which is placed in the centre and a bottom heater located beneath the material. Both heaters are used to prevent excessive heat loss during the experiment. A thin film is first wetted and placed onto the test area, such that there are no creases/wrinkles. Afterwards, the sample is placed coated side down on top of the film. The porous plate unto which the sample is placed has the temperature controlled to a constant rate of 37^{o}C, to match the human body temperature. Once, the sample is placed, the hood is placed over, creating a thermally regulated chamber so the sample, and is usually set to standard conditions (20^{o}C temperature and 65% RH). Each sample generally takes around 30 minutes for the experiment, and the final result is calculated and outputted into the computer. The result is given as the air retention number measured in m^2.Pa/W

4 ANALYSIS OF RESULTS

4.1 SPRAY TEST RESULTS

The aim of this test was to determine the water penetration effects on the coated samples. All of the 5 material sets were tested. The results were graded from 1-5. The results can be seen in the graph below and table in appendix 1. The graph plots the average grade attained from each material set. It shows that the fabric sets 1, 3 and 4 all attained the highest grade which is 4. This grade means that only a slight droplet formation was produced onto the samples. This is an excellent grading, as it is very difficult and rare to achieve a 5 which means no surface wetting would take place at all. Fabric 1 was the material set that was coated with a paste and underwent a post treatment. Material set 3 was pretreated and paste coated and material set 4 was Foam and post treated. The other 2 sample sets had lower ratings with the samples attaining more prominent wet spots.

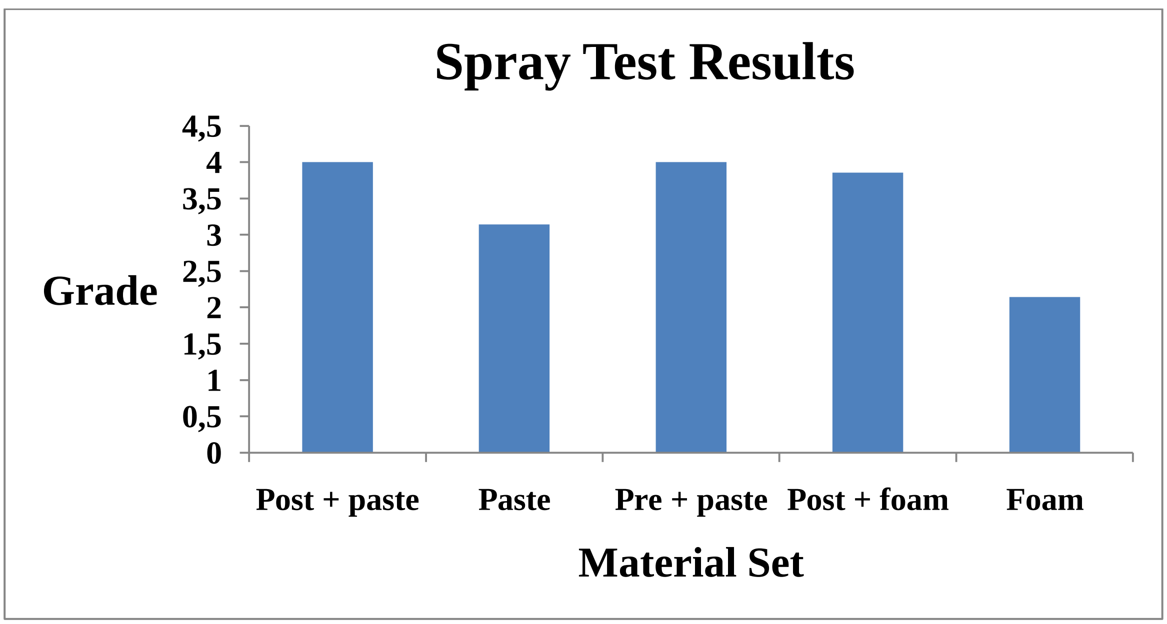


Figure 18: Grade results from spray test

4.2 HYDROSTATIC HEAD TEST

The aim of this test is to determine water resistance effects via penetration. The test was performed for all 5 of the coated material sets. The results were obtained in cm.wg, which stands for the rate of rise in cm of water to give the liquid column pressure. The graph below plots the resultant pressures obtained for each of the sample sets. It can be ascertained that all of the material sets pass in terms of the conditions in ISO 811 which sets the standards to a pressure of 60cm/wg, meaning that all of the different coats are effective for water resistance irrespective of their porosity. The material with a porosity of 2.17% had the highest pressure meaning it is most resistant to the impact of water. Materials with porosity of 0.04% had the lowest value of pressure at 98.5cm.wg meaning that it requires the least amount of pressure to allow water to pass through the material. Nevertheless, it can be construed that all of the results are in a small range from approximately 98 – 102cm.wg which means that all the coats produced similar results. The coats applied onto the material change the permeability of the materials such that there is little or no impact from the different values of porosities.

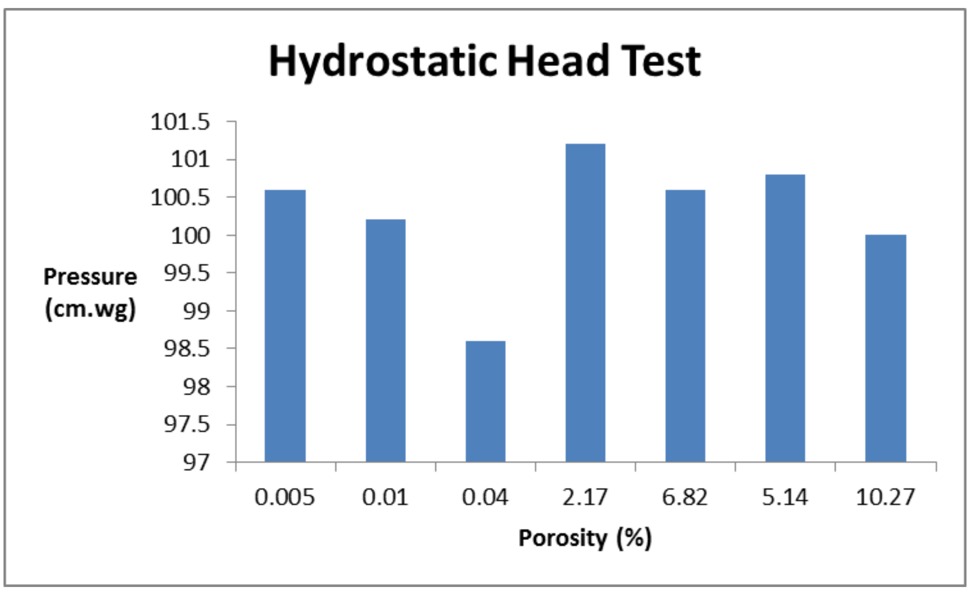


Figure 19: Results from hydrostatic head test in cm.wg

4.3 AIR PERMEABILITY

The aim of this test is to determine the air flow rate for the fabrics. Two sample sets were tested for this; sample set 1 which is the materials that were paste coated and post treated and sample set 5 which were materials that were foam coated and post –treated. Each sample was tested at 10 different positions on the material and the results were averaged. The average is used to calculate the air permeability according to the equation

Air Permeability = $\bar{q}r$ / A .10^{-2}mm.sec

Where $\bar{q}r$ = average of 10 measurements and A = 20 cm^2

The result to the air permeability is given in the table in appendix. The graph below plots the air permeability for each of the coated materials against their different porosities. The first graph is for the paste coated and post treated materials. It can be deduced that despite different porosity values, most materials have a low air flow rate. This proves that all of the various treatments are effective in allowing a small air transfers in clothing, enough to allow evaporation of sweat but still resistant to strong winds. The only exception to this is material with porosity of 6.82%. This material has a high porosity which makes it plausible that the air flow rate is high. However, when compared to the material with a higher porosity this value is bigger which is nonsensical as the higher porosity value should have more permeability. A reason for this peculiarity can be based on the coat that has been applied. It is possible that coat on the material was not uniformly applied, or insufficient chemical finish was smeared onto the surface. Another reason could be from the positioning of the sample when measurements where take, as well as variability of air flow due to external environment, meaning that the valves on vacuum wasn’t tightly clamped or closed. Since the permeability is dependent on an average of 10 readings, it is also possible that the average can be overestimated from a single high value outlier.

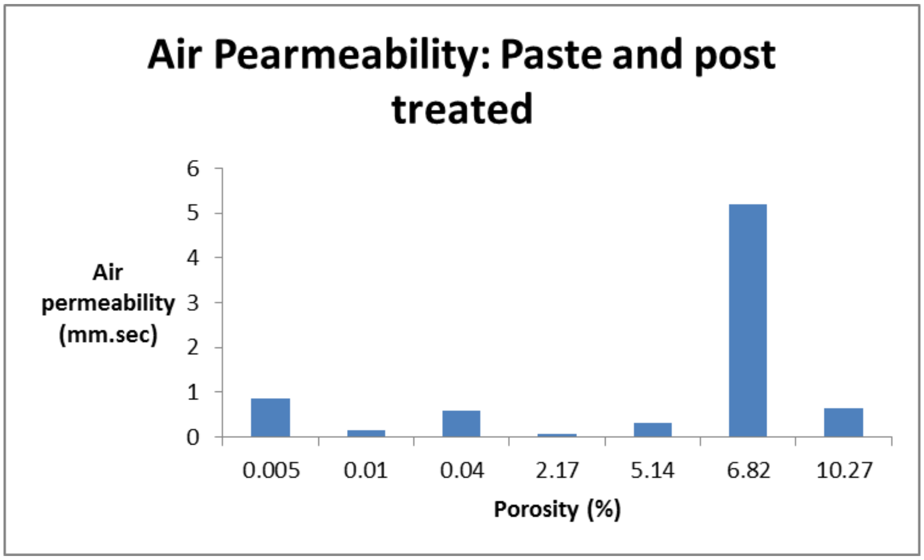


Figure 20: Air Permeability in mm.sec of paste coated and post treated materials.

The second graph plots the air flow against porosity for the foam coated and post treated materials. The results show that all materials have a low permeability rate despite having different porosity. Once again a single material, with a different porosity value this time is markedly higher as compared to the others. The peculiarity could be similar to the previous situation in which the uniformity of the coat is not precise or that the positions in which the sample was measured was not perfect The results also show that for porosities above 1% there is a better flow of air. This is consistent with the knowledge that more pores in the materials allows for improved air flow.

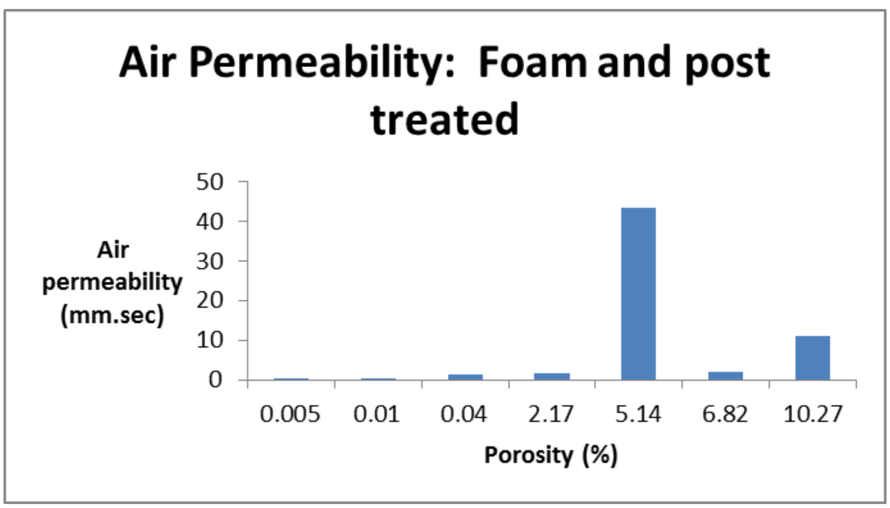


Figure 21: Air permeability in mm.sec for Foam coated and post treated materials.

4.4 BREATHABILITY

This test measures the water vapour permeability by simulating body temperature. The test was conducted with all the samples sets and a deeper analysis is done on the same two sets done in air permeability tests. These where set 1 and set 4, the paste and foam coated materials that had been post treated respectively. They were conducted on the sweating guard hot plate machine which measures the air retention number for each material (Ret). The Ret for the machine with no sample is 4.019 m^2Pa/W, this means that for 1 watt of energy, there is 4.019 Pa air pressure per metre square. The results are given in two separate graphs; one for each set. The first graph (given below) plots the moisture transfer through the material in m2.pa.w against the different porosity values of the sample. The analysis shows that the vapour permeability is high for all different samples regardless of their coats or porosities. This is proved by the results showing only marginal differences in their air retentions. The highest value attained is in the samples with porosity of 2.17%.

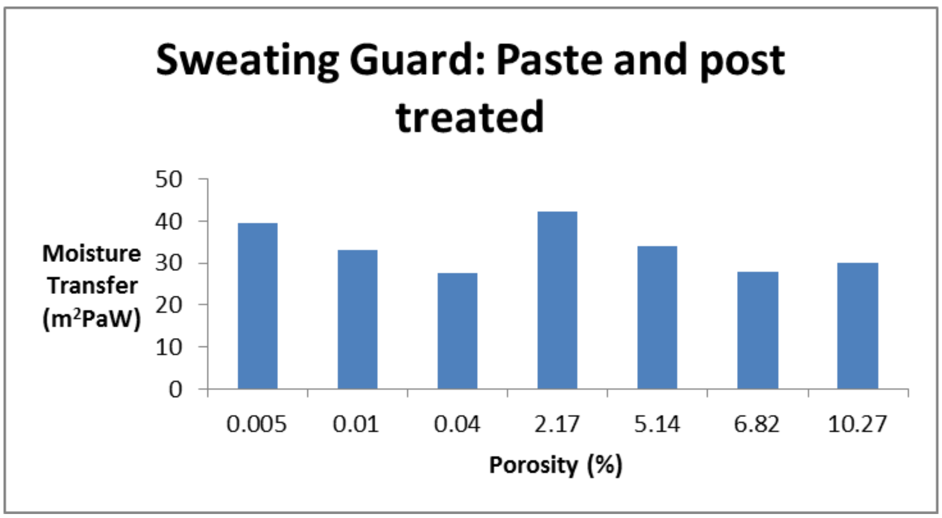


Figure: 22: Sweating Guard Results for paste coated and post treated materials

The second graph plots the moisture transfer effects for the foam treated material. The results show that the fabrics with the smallest pore sizes attained the optimal transfer. This is not concistent with theory, which is that less porosity means lower ability to allow air and moisture to flow through. However, when comparing the result from the rest of the samples, it can deduced that there is an gradual increase in permeability as the porosity increases until a certain value (which is 5.14%) thereafer, it decreases. This trend creates a possibility that the peculiarity shown in the first materials can be due to an external factor. It is likely that the sample as placed incorrectly in the machine (coated side up instead of coated side against the hot plate). The problem could also lie in the membrane containing air bubbles instead of being completely smooth across the hot plate. The rest of results show that the coat provide good breathability properties for all cotton samples, however for optimal results it is best to utilize a material that has a porosity of around 5%.

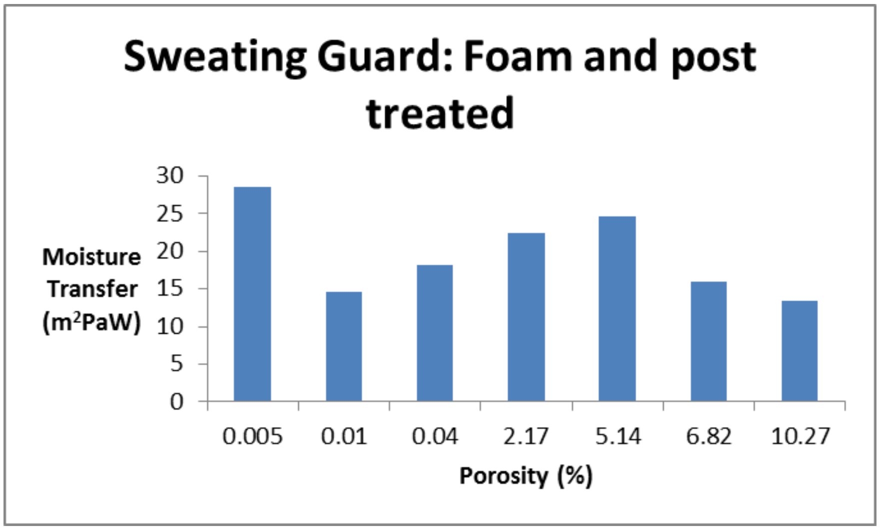


Figure 23: Results from Sweating guard of foam coat and post treated materials.

Finally, the tests were conducted to determine the breathability effects for all samples, in order to compare which coating applications ranks higher. The figure 4.4.3 plots the graph in terms of water vapour permeability in g/m^2.Pa.h. It shows that the foam treated samples has greater vapour transmission as compared to the paste coated materials. The fabrics that underwent a post treatment after foam application had the best permeability at 0.17 g/m^2.Pa.h. It can also be seen that the materials that were pretreated and paste coated had good moisture permeability as compared to the samples that were simply paste coated alone or gone through post treatments.

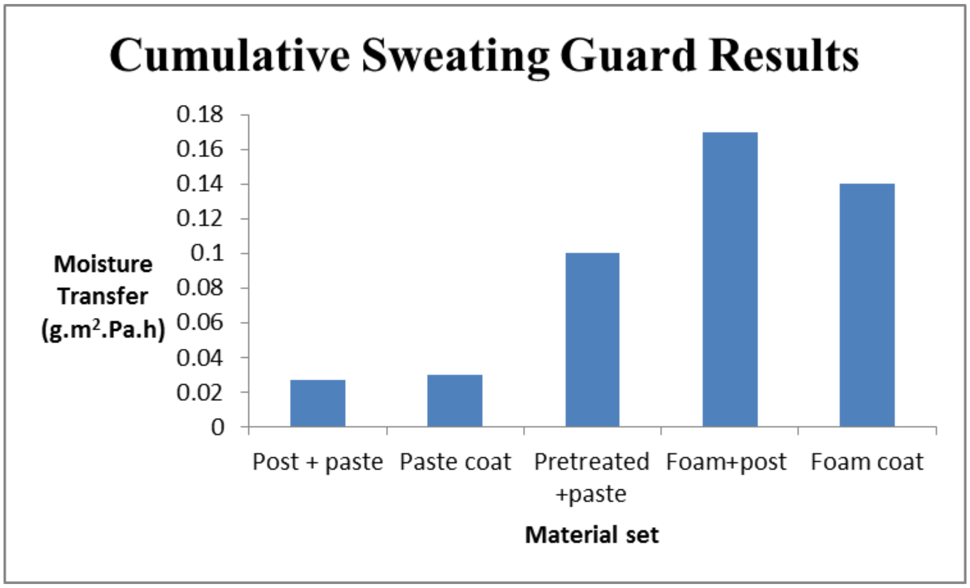


Figure 24: Cumulative Breathability results for all material sets

5 CONCLUSION

The institution of creating hydrophobic textiles requires insight into a variety of aspects. It is essential to understand key factors that may affect the performance of a final product. Since it is possible to achieve water resistance and breathability in materials by their weave structure and/ or chemical finishes, it is necessary to gather as much knowledge as possible about fibers and their fabric contruction as well as a deep understanding of polymeric chemistry. In production, manufacturers utilize this knowledge to create a textile that provides the optimal performance and comfort. This experiment investigated the impacts of using different chemical coatings on the level of hydrophobicity a textile may have. It also determines if the performance of the cotton materials are affected by the level of porosity created in the weave structure.

The tests that were conducted, measured how effectiveness of the applied coats and how they respond to surface wetting, air permeability, water resistance and breathability. It can be ascertained that overall performance of all the coats and additional treatments resulted in materials that have effective resistance to water. This can be confirmed by the spray test results which produced minimal surface wettings as well as by the fact that all samples require a high water column pressure in order to be wetted in the hydrostatic head test. In terms of brethability it can be seen in Figure that all materials managed to a certain degree of moiture transfer. This implies that the coats were successful in achieving their main aim of producing a hydrophobic effect on the samples.

When analyzing the results in terms of determining the best treatment, a common trend can be established from the majority of tests. It can be deduced that materials that had undergone more than the basic coat application, performed better than those that did not. This is most evident in the spray test, as the samples that were pretreated or post treated attained higher grades. The breathability test shows that the foam coated and post treated materials had the best permeability, as well as the pretreated samples also having a good results. Thus, it can be concluded that applying more than just the coat but rather a complimentary chemical treatment can improve the performance of the final product. This is especially for textiles that are pretreated with a fluorocarbon compound and paste coated with an acrylic/polyutherane copolymer compound.

In terms of the impact that different porosities may have on the level of hydrophobicity it can be found they provide a marginal effect on final product. It is expected that the more pores a material contains, the more air and moisture can flow throgh the material. This is not the case when analyzing the results attained in the air permeability and breathability tests. it can be deduced that no matter what the porosity value is the permeability is likely more affected by the coats that have been applied. The results for all indivial tests show that no definitve trends can be found as the value of porosity increases or decreases with the excpetion of the distribution created in the breathability of the foam and post treated materials. the air permeability tests shows that cumulatively all materials have a low air flow rate. However, there seems to be many outlier results and perculiarities, showing that results from this tests can be deemed inconclusive. The breathability tests also show contrasting values, however since the test was conducted once only, it could perhaps be more useful in future research to conduct multiple trials and utilized average results to reduce variability.

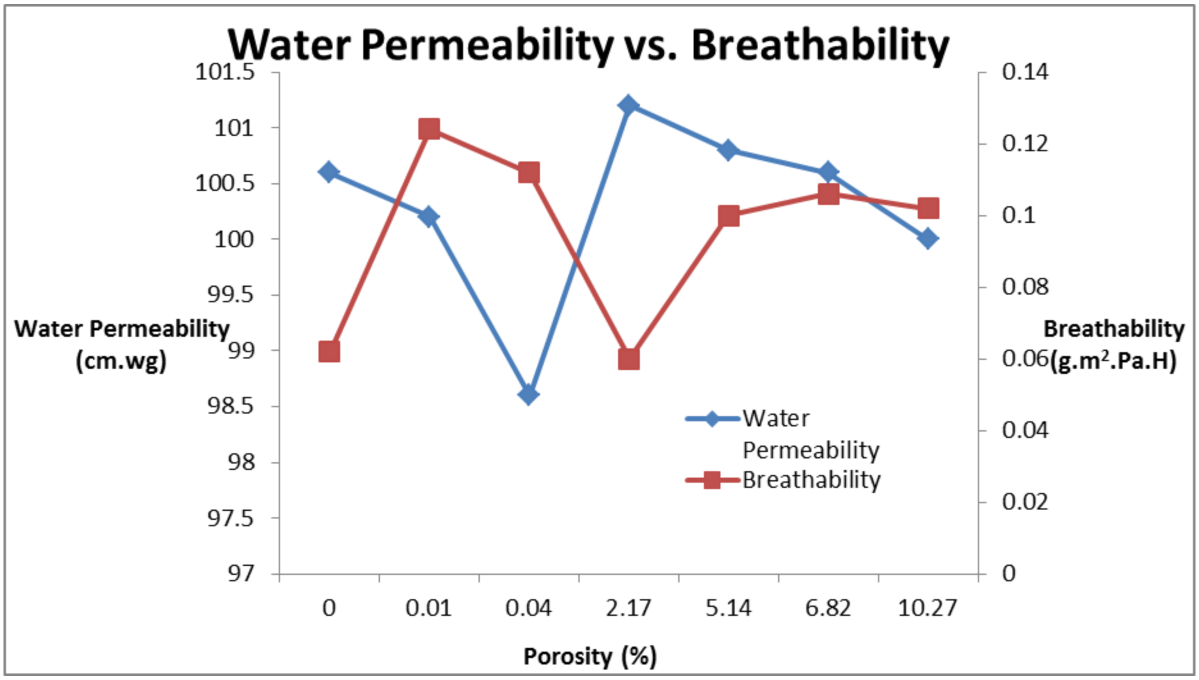


Figure 25: The combined effecst of water permeability and breathability

Breathable and waterproof coated materials can be used in the construction of a wide range of products, from garments to equipment, to automotive parts and so on. For producers decisions are not only based on the aspects in coating but on the understanding that each will provide a different level of resistance and breathability. It is plausible that in order to attain better water resistance, a material might have less breathability. Thus, it is necessary to find and use suitable coats and materials according to the specifications for each single product. This statement is enhanced by the graph given above, which plots the comparative graphs of both water permeability to breathability according to their result to the different values of porosties in the cotton samples. It can be inferred that each level of porosity provides a different level of breathability to resistance. Irrespective of the coat applied the results can conclude that for materials that have a porosity of about 5% and higher have both excellent permeability and breathability. This means that in production of functional clothes such as sportswear, it is better to use a material which construction has a high porosity. But the values of breathability decrease slightly at 10% therefore, in this experiment the optimal is found at 6.82% which has the small deviations in terms of their permeability and breathability.

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7 APPENDICES

Table 1. Results from Spray test

Material	**1**	**2**	**3**	**4**	**5**
Polar	4	2	4	3	2
Sara	4	3	4	4	2
Mitkal	4	4	4	4	2
Platno	4	3	4	4	2
Kepr	4	4	4	4	3
Karel	4	3	4	4	2
Zuzana	4	3	4	4	2
Average	4	3	4	4	2

Table 2. Results from Hydrostatic Head test

Material	**1**	**2**	**3**	**4**	**5**
Polar	97	100	105	98	101
Sara	98	102	105	98	101
Mitkal	98	102	104	97	99
Platno	97	101	104	97	107
Kepr	99	101	104	98	101
Karel	99	100	103	85	106
Zuzana	99	100	102	97	105
Average	98.14286	100.8571	103.8571	95.71429	102.8571

Table 3: Results from Air Permeability for paste and post treated samples

qr	**Polar A1**	**Sara B1**	**Mitkal C1**	**Platno D1**	**Kepr E1**	**Karel F1**	**Zuzana G1**
1	0.24	1.1	0.5	0.1	0.16	1	13
2	0.52	1	1.4	0.2	0.18	1.7	10
3	0.3	1.1	0.6	0.42	0.12	0.9	11
4	0.36	0.9	0.7	0.2	0.14	1	19
5	0.37	0.7	0.7	0.1	0.1	1	18
6	0.25	0.5	2.4	0.12	0.24	1.2	10
7	0.2	0.2	3	0.1	0.25	1.3	8
8	0.32	0.18	1	0.12	0.2	1.2	5
9	0.34	0.4	1.5	0.1	0.18	1	4
10	0.34	0.4	1.1	0.2	0.14	1.3	6
average q¯r	0.324	0.648	1.29	0.166	0.171	1.16	10.4
Air Permeability	0.162	0.324	0.645	0.083	0.855	0.58	5.2

Table 4 : Air permeability of Foam and Post treated materials.

qr	**Polar A4**	**Sara B4**	**Mitkal C4**	**Platno D4**	**Kepr E4**	**Karel F4**	**Zuzana G4**
1	1	60	45	2.8	0.8	3	3.3
2	1.5	95	10	2.3	0.4	2.4	5.6
3	1	75	38	2.8	1	1.9	4.2
4	1.3	140	30	3	0.7	3	5
5	0.9	100	8	3.6	0.8	2.8	7
6	0.6	110	24	3.6	0.5	2.7	4.9
7	0.5	130	14	2.8	1.2	2.3	2.3
8	0.9	50	8	3.6	1.3	2.8	2.2
9	1	55	20	2.7	0.9	2.7	3
10	0.6	50	22	3.1	0.7	3	2.2
average q¯r	0.93	86.5	21.9	3.03	0.83	2.66	3.97
Air Permeability	0.465	43.25	10.95	1.515	0.415	1.33	1.985