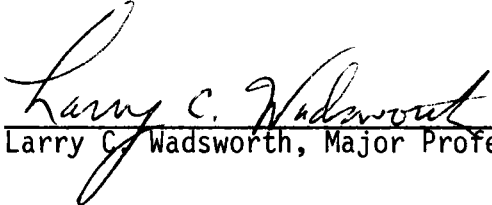
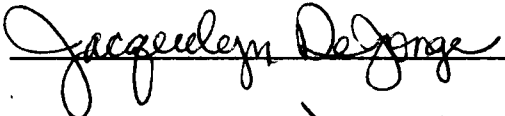


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A STUDY OF THERMAL BONDING OF MELT BLOWN AND SPUN-
BONDED LAMINATES AND REPELLENT FINISHING
TECHNIQUES

A Thesis
Presented for the
Master of Science
Degree

The University of Tennessee, Knoxville

Lisa M. Salamie
June 1987

DEDICATION

This thesis is dedicated to my parents, Dick and Diana Salamie.

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ABSTRACT

In this study more effective methods of applying a fluorochemical finish to relatively inexpensive melt blown/spunbonded (MB/SB) nonwoven laminates produced in the Textile Materials Research Laboratory were investigated with respect to improved performance and lower cost. The two possible end-uses for the MB/SB laminates are operating room drapes and gowns and apparel for agricultural workers, such as, pesticide applicators. In addition to comparing finishing techniques, the thermal bonding sequence of a MB/SB laminate before and after finishing also was studied to determine the effects on repellency, barrier properties, laminate bonding strength, air permeability, and drapability.

Polypropylene melt blown webs produced on the melt blown pilot line at UTK were laminated with an experimental point bonded spunbonded polypropylene fabric obtained from Du Pont. Polypropylene melt blown and spunbonded laminate samples were thermally bonded with a smooth roll calender both before and after fluorochemical (FC) finishing by the more conventional padding technique and by two low wet pickup methods, foam finishing and kiss roll applications. Repellency (oil, alcohol and water repellency) and barrier properties (water impact resistance and air permeability), and bonding strengths were examined.

Surprisingly, the MB/SB laminates, which were thermally bonded prior to finishing, picked up substantially less finish due to decreased porosity, and had much improved oil and alcohol repellency. The foam finished laminates had the highest oil and alcohol repellency

values followed by those prepared by kiss roll and finally the padding techniques. Although all of the finished MB/SB laminates had excellent water spray ratings and water impact penetration resistance (due to the barrier properties of the melt blown component), the key to oil and alcohol repellency appears to be the concentration of FC finish deposited on the outer surface of the laminate.

Generally, the thermally bonded laminates had somewhat lower air permeability, as compared to the unbonded laminates. The melt blown and the spunbonded components separately had appreciably higher air permeability. However, the air permeability values of the MB/SB laminates, which were thermally bonded before FC finishing were generally higher than a slightly lower weight commercial spunbonded/melt blown/spunbonded (SMS) fabric, which had been thermally point bonded. Laminate bonding strengths were much lower than the commercial point bonded SMS fabric, but were believed to be suitable for protective clothing application.

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INTRODUCTION

Suitable disposable protective clothing is needed for medical and agricultural purposes. These protective fabrics must provide a barrier to bacteria and harmful chemicals, yet be comfortable to the wearer. The objective of medically protective clothing is to protect both the patient and the surgical staff, whereas agriculturally protective clothing is worn to protect the wearer. The wetting of scrub gowns and operating room (OR) drapes, a common transport medium for bacteria, increases the incidences of post operative infections among patients. In addition patients and workers in the medical profession need protection against liquids that serve as a transport medium for bacteria.

Although the medical industry has no Federal Standards to determine the efficacy of medically protective clothing, they follow the guidelines of the American Association of Operating Room Nurses (AORN). The American Association of Surgeons have adopted the AORN guidelines which requires the fabric to pass certain repellency and barrier tests. The conscientiousness of the medical industry in regulating the efficacy of these protective garments motivates the manufacturer and suppliers to improve barrier and comfort properties, as well as, cost performance of these products. Even the Environmental Protection Agency recently has begun to fund research for the purpose of evaluating protective apparel fabrics and procedures for agricultural workers who are regularly in contact with hazardous and volatile chemicals associated with pesticides.

Currently agricultural workers are not giving serious consideration to protecting themselves from exposure to toxic pesticides (Branson, 1986). Unless these garments offer high protection at low cost, most agricultural workers would not bother with wearing disposable protective garments, thereby decreasing his chances for developing serious agriculturally related illnesses. Research has shown that comfort is a great factor in selection of garments than protection (DeJonge, 1983). Even though the guidelines of the United States Federal Register specifies that tightly woven fabric should be worn during pesticide application, it well known that the wicking process of a tightly woven fabric can transfer pesticide solution to undergarments or skin at a faster rate than that of loosely woven fabrics (Freed, et al. 1980 and Federal Working Group on Pest Management, 1974). Depending on the construction of the nonwoven web, certain finishing and thermal bonding techniques, such as point bonding, can produce nonwoven fabrics which are porous, but still suitable for protective clothing.

The primary focus of this study is to develop more cost-effective methods of thermal bonding laminates and to apply finishes to relatively inexpensive fabrics--melt blown/spunbonded polypropylene nonwoven laminates. Manufacturers could pass these savings on to the customers in the form of low-cost, highly repellent, durable, disposable and comfortable protective clothing. Furthermore, if the protective fabric is suitable for medical use, then it should be acceptable for agricultural purposes. Not only could these protective garments be marketed for agricultural and the medical workers,

but endless markets may well exist for other fields including infant and nursery care, toxic waste disposal facilities, food service operations, and mining operations.

The objectives of this study were:

1. To examine the effects of water, oil and alcohol repellency performance on fluorochemically (FC) treated point bonded spunbonded polyolefin fabric. FC finishing should improve the repellencies of spunbonded fabric; however, it is believed that the fabric will not have good resistance toward barrier tests such as the water impact penetration test.
2. To develop a nonwoven fabric with improved barrier performance by laminating a melt blown web with the spunbonded fabric. The function of the spunbonded fabric would be to provide strength for the laminate, whereas that of the melt blown fabric would be to provide barrier properties for the laminate.
3. To achieve the successful thermal bonding of the melt blown/spunbonded (MB/SB) laminates by utilizing a smooth roll calender that is available in the university laboratory. By using a fairly thick spunbonded fabric which already has a point bonded pattern, it should result in a point bonded type contact with the melt blown fabric during overall smooth roll calendering.
4. To improve oil and alcohol repellency and barrier performance of MB/SB laminates by applying a fluorochemical repellent finish.
5. To determine whether the best barrier and repellency properties could be obtained by repellent finishing the melt blown and spunbonded components before thermally bonding or by repellent

finishing the laminate after it has been thermally bonded. It is believed that the first method should have a higher take up of finish, whereas in the second method the fabric, which is less porous after bonding, should result in lower take up of fluorochemical finish.

6. To determine the most feasible technique for applying repellent finish by comparing two low wet pickup methods, which are kiss roll and Foam Finishing Technology (FFT) applications, with the more conventional padding method, a saturation technique. The kiss roll and FFT applications would be faster and more economical from the standpoint that less water is applied to the substrate and therefore, less energy is required in the drying process. Better properties possibly could be obtained with low wet pickup techniques in that there is direct chemical deposition on the surface of the fabric.

CHAPTER I

TERMINOLOGY

Any attempt to develop more cost effective methods of applying finishing techniques for protective clothing includes an elementary knowledge of barrier properties, polypropylene fabrics, and existing finishing techniques. This chapter presents a brief review of these topics to serve as background information for better understanding of this study.

1.1 ELEMENTARY KNOWLEDGE OF BARRIER AND COMFORT PROPERTIES

It is difficult to combine both barrier and comfort properties in protective clothing. Protective garments should simulate certain processes of the skin such as regulating the temperature, providing protection, and providing comfort. A protective fabric with ideal barrier properties has large enough pores or "voids" to allow moisture vapor to escape, yet the pores are small enough to prevent liquids, particulates, or bacteria from entering. When the moisture vapor cannot escape through the fabric, then the moisture condenses, causing hot, sticky, clammy discomfort to the wearer. If chemicals or pesticides are allowed to penetrate through the porous fabric, they consequently may be absorbed by the skin, possibly causing harmful side effects. Hence, a basic understanding of such barrier properties as moisture vapor transmission, wetting, wicking, and permeation of chemical liquid can lead to improved and more applicable protective garments.

1.1.1 Moisture Vapor Transmission

The evaporation of a high concentration of water on the skin occurs through the process of moisture vapor transmission. When heavy perspiration occurs, the moisture transfer property of protective material becomes important despite condensation build up within the textile layer. For instance, condensed moisture in the middle layers of clothing can work back to the inner, warmer textile layers. Louis Weiner (1971) explains that the extra heat loss between the body and its cooler environment exists due to the recurring transmission of moisture between the warmer and cooler layers of clothing. Thus, moisture vapor transmission phenomena must be a consideration in the development of comfortable fabrics for protective garments.

1.1.2 Wetting

In the selection of appropriate protective material, it is helpful to have a knowledge of its wetting characteristics, such as, contact angle and surface energy of the fiber. Branson (1980) defines contact angle as "the plane of the surface contacting a liquid drop and the tangent to the drop at the point of contact." Contact angle magnitude is determined by the independent interfaced tensions between air, liquid and solid. For instance, when two solids are wetted with the same liquid, the solid with the most affinity for the liquid results in a smaller contact angle.

According to Branson (1980), the surface free energy of the fiber is "a measure of the ability of a fiber to adhere to itself." Generally, all fibers have lower surface energy than water. If a

fiber surface free energy is closer to water, it can be more easily wetted. However, the hydrophobic or hydrophilic nature of the fiber can have a greater effect on wetting than surface energy alone.

1.1.3 Wicking

Wicking is an important characteristic that facilitates comfort. Heat stress can cause a protective garment to be uncomfortable. Unless protective clothing is comfortable, its wearer's will shun its use.

Branson (1980) points out that wicking strength exists in the number of capillaries found in fibers. Moreover, wicking is affected by the radius of the capillary, viscosity of the liquid, surface tension of the liquid, fabric type, yarn structure, and finish of treated fabrics. Wicking can occur when the required amount of water has filled the capillaries that are produced between fibers and yarns. According to Branson (1980), penetration of liquid through the fabric can be reduced by minimizing capillary action through knowledgeable selection of fibers, yarns, or fabrics.

1.1.4 Permeation of Chemical Liquids

Permeation of chemical liquids through clothing, as explained by Ainsworth (1971), occurs when the liquid can spread as it is confined into the capillary structure of the outside fabric. Then it vaporizes through the layers between the fibers of the yarn. The wet outside layer diffuses through the inside layer, as well as, into the atmosphere. When the layer of chemical forms on the surface of the skin, the skin can quickly absorb the vapor which diffuses through the

epidermis into the vascular system. The contaminated clothing slows down the rate of chemical evaporation to the atmosphere compared to the rate of evaporation from the skin. Hence, clothing can create a substantial risk where there are highly volatile chemicals even in small amounts (Ainsworth, 1971). Skin absorption of chemicals may have a gradual and cumulative effect which is difficult to predict.

Ainsworth (1971) also found that the amount absorbed at the surface of the skin is proportional to the saturation concentration of the vapor. This includes substances of low volatility which can be hazardous when they permeate through clothing in the vapor phase. Long after the contamination event, the outside layer of clothing can propose a hazard to the respiratory system due to the lingering chemical vapors.

According to Williams (1980), there is no practical material available that can provide protection from all chemicals. The best way to select proper protective attire is to test the hazardous chemical that would be subjected to the proposed material. From these findings, the appropriate protective material can be selected with a knowledge of its breakthrough time.

1.2 ANALYSIS OF POLYPROPYLENE FABRICS

In today's textile industry, polypropylene is an inexpensive, versatile fiber that can be processed at most conventional nonwoven installations. The following section offers a background presentation including: (1) characteristics of polypropylene fibers, (2) types of

polypropylene processes, and (3) an explanation of the thermal bonding of polypropylene fabrics.

1.2.1 Characteristics of Polypropylene Fibers

Although polypropylene has been marketed for nearly half a century, the general public has not accepted it in their standard wardrobe. Nevertheless, polypropylene possesses enormous potential as a marketable fiber for the nonwoven industry because of its excellent properties. Generally, nonwoven fabrics made of polypropylene have the following major characteristics: high abrasion resistance, an inherently good water repellency, high wickability and high strength. More complete properties of polypropylene webs are given in Table I.

Table I. Attributes of Polypropylene in Nonwovens.

(Source: Adapted from Richard G. Mansfield "Polypropylene in Nonwovens: Products and Participants," Nonwovens Industry, February 1985, p. 26.)

-
-
- High strength
 - High abrasion resistance
 - Low specific gravity--high covering power
 - Ability to fibrillate--synthetic pulps
 - Can be thermal bonded and thermoformed
 - Processable on most conventional equipment
 - High wickability
 - Can be made into microdenier structures
 - Can be made into smooth, soft structures
 - Overall favorable price/performance properties
 - Good chemical resistance
-

1.2.1.1 High abrasion resistance. High abrasion resistance, or durability, makes polypropylene well suited for garments subjected to heavy use, such as disposable protective clothing worn by agricultural and medical personnel. Durability means that a polypropylene fabric can withstand a "day's work" without major wear or tear before it is properly disposed. This abrasion resistance property is the result of smooth fibers and the resulting low surface energy. In addition, its favorable volumetric yield is derived from the low density of the fiber. In turn, the high yield is a cost effective feature since it enables more fibers to be produced at a lower cost. Relatively low production costs make polypropylene fabric ideal for disposable garments.

1.2.1.2 Inherently good water repellency. A fabric's inherent water repellency property, the ability of the fiber to repel liquids (specifically oil and water based pesticides used by agricultural workers) is a result of the low surface tension of the fiber. By adding a fluorochemical finish to the polypropylene substrate, the surface tension of the fiber can be lowered to values near 25 dynes/cm. Comparatively, the surface tension of untreated polyolefin is 31 dynes/cm while popular synthetic fibers, such as polyester, are 43 dynes/cm and nylon 6,6 is 46 dynes/cm. The repellency or nonwetting of polyolefins is related to the higher contact angles of such liquids as water and other high surface tension liquids with values above 31 dynes/cm. Ideally, the lowest surface energy that can be achieved is with polytetrafluoroethylene whose surface energy is 18 dynes/cm (Kissa, p. 151, 1985).

The reason for its inherent repellency property is that it does not possess polar groups which assist in hydrogen bonding. Hence, it is this hydrophobic nature of the fiber and its good chemical resistance make it suitable for use in protective clothing.

1.2.1.3 Wickability. The wickability of polypropylene enhances the comfort of the garment despite the low moisture regain of polypropylene. For instance, the inner layer of polypropylene fabrics can wick perspiration from the skin by allowing it to absorb and evaporate at the fabric surface. Because of the wickability of polypropylene nonwovens, they are ideal for protective wear applications.

In 1980, Beryl Kuhn's studies found that commercial polypropylene fibers wick rapidly. According to Kuhn, this tendency may be attributed to the hydrophobic lubricant on the surface of the fiber and not the inherent hydrophobic nature of the fiber itself. The lubricating surfactant modifies the low surface energy causing the fiber to wick. Decreased wickability results when the surfactant is removed during washing. Subsequent research by P. Harnett and P. Mehta (1984) substantiated Kuhn's earlier findings. However, wicking may still be an important factor with melt blown and spunbonded polypropylene fabrics which do not contain fiber finish due to the much greater number of small pores in these fabrics.

1.2.1.4 High strength. Its high strength occurs when polypropylene is drawn or attenuated to orientate its molecules in a direction parallel to the fiber axis. As the draw ratio increases, so

does the degree of molecular orientation. Depending on the application, the same batch of polypropylene can be produced in a wide range of tenacities and molecular orientation.

1.2.2 Types of Polypropylene Nonwoven Processes

Mansfield (1985) has projected that by 1988 over 400 million pounds per year of polypropylene resins will be produced. These resins will be developed into all types of nonwovens, including dry-laid, needlepunched, wet-laid, spunlaced, spunbonded and melt blown nonwovens. This section continues to discuss two types of polypropylene nonwovens processes related to this research: (1) Polypropylene spunbonding process and (2) Polypropylene melt blown process.

1.2.2.1 Polypropylene spunbonded process. Wadsworth and Goswami (1983a) discussed the du Pont process of spunbonding which consists of extruding continuous synthetic filaments which are then drawn before they are randomly laid on a conveyor belt. Here, immediate bonding results when undrawn filaments with lower melting points join the extruder (drawn) filaments. The Freudenburg process, another spunbonding method, involves more extensive bonding which is accomplished by thermal point embossing or by saturation with adhesive latex.

The many advantages and characteristics of spunbonded nonwovens have made them the fastest growing fabrics in the nonwoven industry. For example, the polypropylene filament fibers of spunbonded substrates have greater tensile and tear strength in both machine and

cross direction than do nonwovens derived from staple fibers. Moreover, these fabrics have the reputation for being the stiffest of the nonwoven substrates. However, this stiffness does not usually present a problem in that the fabrics are so strong that the weight for many applications can be reduced to as low as 0.4 ounces per square yard. By reducing the weight and consequently the thickness, the drape and the "handle" properties of the spunbonded fabric as well as the spunbonded component of a laminate are improved. Its hand is firmer, making it more durable and not as bulky as dry-laid staple fiber webs. However, spunbonded fabrics do not have the high cover factor of the melt blown fabrics since spunbonded fabrics have greater diameters.

By the next decade, Mansfield (1985) projects that over 400 million pounds of olefin spunbonded nonwovens will be produced annually in the United States. At the present time, Kimberly-Clark is the nation's largest producer of spunbonded polypropylene. The company manufactures numerous hospital and medical products from this fabric. The future looks even more promising for numerous unique applications of spunbonded fabrics.

1.2.2.2 Polypropylene melt blown process. The production of the microdenier polypropylene fiber is a direct thermal process from polymer chip to the melt blowing process. In the extruder, the polypropylene pellets are melted and then heated to the prescribed temperature for melt blowing. Various extruder temperatures are needed to accommodate the specific end-product and molecular weight of

the polymer. The polymer leaves the extruder and enters the melt blowing die, the essential component of the total process. The heated primary air, which is feed across both sides of the row of spinneret holes of the melt blowing die, attenuates the molten polymer as it exits the die. Secondary ambient air cools the fiber as it continues from the die. Hence, the drawing and cooling stages of the fiber takes place at a short distance from the die tip. In addition, the thermoplastic polymer webs can vary in size and properties depending on air flow rate employed in the melt blowing process and the distance of the take-up device from the opening of the die heads. At higher air rates, for example, the fibers are drawn down to smaller diameters. When the product application requires extremely fine fibers, melt blown nonwovens are the popular choice.

Melt blown nonwovens offer various practical advantages for the consumer in today's market. For one, polypropylene can be formed into diverse deniers and textures. This is possible because the melt blown process is capable of producing diameters from 2 to 5 micrometers. These smaller denier polypropylene fibers are ideal for filtration and barrier purposes, and they also allow breathability which makes them highly suitable for comfortable protective clothing. Since the melt blown web of microdenier fibers produce channeled micropores, it allows the transfer of moisture vapor which gives it the quality of breathability. Another advantage of melt blown nonwovens is that the larger surface area improves filtration and barrier properties. Fabrics with these properties are highly marketable. Unfortunately, melt blown webs of less oriented fibers are not as strong as the

spunbonded nonwovens. Thus, the synergistic effects of melt blown/spunbonded laminates increases the advantages for protective apparel use.

Commercial uses of melt blown nonwovens have been increasing in recent years as manufacturers, like Kimberly-Clark and the 3M Company, have combined polypropylene melt blown nonwovens with other fabrics to produce composite nonwoven fabrics. The 3M Company also applies melt blown technology to the production of surgical and industrial face masks. Other companies, such as Chicopee and Surgikos, manufacture melt blown products, like panty shields, a type of sanitary napkin. The James River Corporation markets melt blown polypropylene and polyester fabrics under the trade name "Polyweb" for conversion by other companies into surgical face masks and various types of industrial filters.

Commercially, Exxon Chemical Company has been at the forefront in developing a totally commercially feasible melt blowing process. Exxon does not manufacture melt blown nonwovens but has licensed over twenty companies, world-wide that are involved in the research and the manufacturing of melt blown fabrics. Exxon continues to be active in the development of polyolefins that are custom-made for melt blowing. Exxon maintains its only two pilot lines, 10-inch and 20-inch width melt blown lines, in the Textile Processing Laboratory at The University of Tennessee, Knoxville.

1.2.3 Thermal Bonding of Polypropylene Fibers

Thermal bonding is one method of combining melt blown/spunbonded (MB/SB) composites. The thermal bonding method consist of applying

heat to bond layers of fabric together. The way in which this is done influences material strength and stiffness; therefore, it is important to discuss in greater detail the different methods of thermal bonding MB/SB laminates.

1.2.3.1 Advantages of thermal bonding. Thermal bonding offers certain advantages over chemical binders. It decreases energy costs by eliminating the drying process, a required step in the application of wet adhesives. Vogel (1984) noted that it is a cleaner operation since the process requires less chemical binders in the end product. Skin and eye irritations are minimized as resin bonding of nonwovens is eliminated. Ward (1983) has noted it is an energy efficient process; it has a low melting point of 161°-163°C. Hence, less thermal energy is required to heat the calender. However, during the thermal bonding process the melting point of the thermoplastic fiber and the weight of the substrate must be taken into careful consideration in adjusting thermal bonding process conditions.

1.2.3.2 Selected thermal bonding methods. Specific methods of thermal bonding are chosen according to appropriate web substrates, end-use, and surface of the material to be treated. One method has been developed in West Germany by Fleissner GmbH and Company. This method is a process which uses a through air heater to heat the web prior to entering the nip point of the thermal bonding unit. Furthermore, the heating function of the calender is reduced leading to greater output speeds (Ward, 1983). A different method used by the Kusters Company employs heated steel rolls which permit the nonwoven

substrate to be bonded on either side; this improves the bond. But whatever the specifics, the thermal bonding of lightweight nonwovens on a calender machine is a better choice than wet polymer bonding methods (Bradshaw, March 1984).

Thermal calenders may have smooth rolls for uniform bonding throughout which usually produces a stronger, but stiffer fabric or the steel calender roll may have a point pattern which only bonds thermoplastic fibers or laminates at the raised points of an embossing pattern. The proper selection of the point or embossing pattern can result in a nonwoven which has more strength as well as a better hand. The textured cloth-like point bonded nonwovens are more flexible because the point bonded area consist of only 5-25% of the total nonwoven area.

Wadsworth and Goswami (1983a) note that the diameters of the patterned rolls in the thermal bonding process are designed so that they correlate with the application width of the calender. The patterned impression may be on one or both sides. They caution that it is important to achieve even pressure across the application width of the nip. They further suggest that crowned support rolls can be used to counteract the heavy working nip pressure. This counteraction is done by symmetrically decreasing the roll diameter by a fraction of a millimeter from the middle to the ends of the rolls. Wadsworth (1983a) emphasizes that accurate temperature regulation of roll temperature with plus or minus 1°C of bonding temperatures up to 225°C is important regardless of whether one or both rolls are heated.

Ultrasonic web bonding is another method of thermal bonding. According to Wadsworth and Goswami (1983a) this method involves a system of point bonding which is especially appropriate for bulky webs and composites. A small area of pattern bonding maintains the bulk of each constituent. The ultrasonic energy with its vibrating pin projections softens the fibers at the pins' point of contact on the pattern roll. Only the materials to be combined are heated, but not the pin projections or the patterned roll.

1.2.3.3 Melt blown/spunbonded laminates. Nonwovens, such as melt blown and spunbonded fabrics, are ideal for composite structures since their physical characteristics, such as strength, softness, bulk, and fineness, make them quite versatile, economic, and suitable for a wide range of applications. Manufacturers must decide which fabric characteristics are relevant for their end use, which features are expandable, and which fabric needs enhancement.

Naturally, combining composite materials depend on the composition of the nonwoven. For instance, Du Pont developed a spunbonded olefin, Tyvek[®] which is practical in protective clothing application. When Tyvek is laminated with Saranex[®], a patented film processed by the Dow Chemical Company, this treatment effectively decreases the penetration rate of most liquids including many organic and inorganic chemicals. The hydrophobic properties of polyethylene fibers is basically accountable for the chemical and biological inertness of the fabric. Du Pont claims that Tyvek provides an effective barrier to particulates as small as a half-micron in size

(Silk, August 1983). Even though Tyvek laminates are effective barriers toward most chemicals, they generally are not as comfortable as other protective clothing which have greater porosity.

The melt blown/spunbonded laminates have a synergistic effect as one nonwoven enhances the other one. For instance, the spunbonded fabrics provide strength, durability and abrasion resistance while the melt blown fabric serves as a protective barrier without prohibiting the air permeability process. Further the microdenier fibers of the melt blown fabric provides a greater surface area which results in excellent filtration and barrier properties. Since spunbonded fabrics have high tensile and tear strength, less bulk, and more firmness, its combination with the melt blown fabric should be ideal for protective clothing purposes. Depending on the porosity of substrate, the barrier properties can be improved by fluorochemical finish, without sacrificing the melt blown/spunbonded characteristics.

Mansfield (1985) discusses several melt blown/spunbonded composites now available on the market. For instance, he noted that Kimberly-Clark has combined melt blowing with the Lurgi spunbonded process making composite structures for a variety of product applications. One of these successful products is Kimguard[®], a surgical wrap. This surgical wrap is actually a spunbonded/melt bonded/spunbonded (SMS) composite, where a layer of melt blown polypropylene is inserted between two layers of polypropylene spunbonded fabrics. It is designed to permit ethylene oxide or other sterilants to permeate the closed package to sterilize the equipment, yet does not allow bacteria to penetrate the package. He also

discusses another Kimberly-Clark product known as Spungard[®], an SMS product similar to Kinguard. Spungard provides many special characteristics such as good breathability, comfort, absorbancy, strength, and conformability. It also provides a barrier to bacteria because of the extremely fine polypropylene microfibers. Spungard is marketed for surgical gowns. These fabrics which are suitable for surgical gowns would generally be suitable for protection from pesticide applications, also.

Two other SMS fabrics by Kimberly Clark with commercial names SafeGuard CPF[®] and DuraGuard[®] have several advantages according to Ward (1982). First, both protective fabrics are designed to accommodate the customers' need since different weights are available for different environmental protection purposes. Second, both protective fabrics provide a barrier against liquid splashes, and acid or caustic spray or splatter. Lastly, they are breathable, lightweight, strong, durable and non-linting. All of these advantages should make these fabrics highly suitable for pesticide applicators.

1.3 FINISHING TECHNIQUES

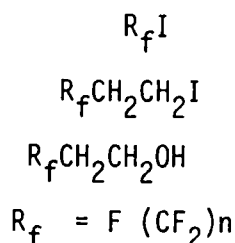
The textile industry traditionally has applied a fluorochemical finish either by a padding process, which is a saturation technique, or by a spraying process. Afterwards, the finished fabrics are dried and cured over heated drying cans or through an oven. One of the objectives of this work is to investigate the attributes of the melt blown/spunbonded (MB/SB) laminates treated by the more widely used

padding method. The attributes of the two new low wet pickup methods (kiss roll and FFT methods), which are finding increased use in the textile industry, will also be studied. Low wet pickup methods result in less water being picked up by the fabric from the finish liquor, thereby requiring less energy to dry the fabrics. Thus, the latter process should result in the required repellency properties at a lower cost.

1.3.1 Fluorochemical Finishes

Strickler (1984) explains that fluorochemicals can be used to achieve the repellency of low surface energy fluids. The nonwovens used for medical purposes must be resistant to low surface tension fluids such as soaps, oils and alcohols, whereas in pesticide applications the finish is used to prevent the penetration of water or oil based pesticides, as well as, detergents used as dispersing agents. However, medically protective apparel requires greater oil repellency than pesticide protective apparel because the oils found in pesticides have relatively higher surface energies than those that are encountered in operating rooms.

According to Strickler, fluorochemicals refer to various kinds of fluorine-containing compounds in which hydrogen atoms are substituted with fluorine atoms. But, in perfluoro compounds (R_f), all the carbon-bonded hydrogen atoms in the parent radical are substituted with fluorine. In addition perfluoro compounds contain a perfluoro side-chain bonded to a chain with a reactive group (I) for further chain growth. Strickler gives the basic steps for producing perfluoro compounds as follows:



Where the average value for n is 8. These polymers are incorporated as polymeric systems which are usually dispersions or emulsions. Aqueous systems consist of either cationic, anionic or nonionic emulsions or dispersions.

Further, he discussed the performance properties of a fluorochemically treated surface. He notes that a good fluorochemical treatment depends upon the contact angle between the liquid that touches the surface and the critical surface tension of that surface. A decrease in surface tension of a liquid leads to a decrease in the contact angle, hence the solid surface wets more easily. On the other hand a decrease in critical surface tension causes an increase in the contact angle resulting in a more repellent surface. He believes that at least 50-70% of the fluorochemical must cover the surface of the fabric to achieve good repellency. The amount of surface coverage depends on the type of finish application, and it affects the values of the advancing and receding contact angles. According to Strickler, about 800 to 1000 ppm fluorine is needed for good coverage of nonwovens depending on the construction and performance of the fabric. Since fluorochemicals do not form continuous films, they do not make a typically porous nonwoven fabric would not be completely resistant to fluids and permeation. On the other hand, the melt blown/spunbonded

laminates already have good barrier properties which are attributed to the melt blown component.

The primary advantage of fluorochemical finishing on polypropylene would be to impart greater oil repellency to these fabrics since the hydrophobic fibers already have good water repellency. Hydrophobic fibers (such as polypropylene) require wetting agents during finish application to overcome this property. Maximum surface coverage is achieved through the wetting agent which permits the substrate to absorb more of the finishing solution. It has been demonstrated that wetting agents can increase the wet pickup of polypropylene fabrics from a natural low of 25% up to 105% with a wetting agent.

It is economically feasible to extend fluorochemical finishes with the aid of water repellent extenders. Hydrocarbon finishes, a water repellent used with fluorochemicals, improve water repellency, whereas fluorochemical finishes improve both oil and water repellency. Since hydrocarbon finishes are much less expensive to use, they are added to the fluorochemical finish formulation to reduce the costs. So, with the proper ratio of fluorochemical to hydrocarbon extender, it is still possible to achieve both good oil and water repellency.

Strickler also considers curing to be an extremely important step in fluorochemical finishing as it allows the fluorochemical finish to melt, spread, and orient the fluorochemical chain ends upward from the surface. These fluorochemical chain-ends or tails orient themselves away from the fiber producing a low surface energy barrier. The result is resistance to wetting and permeation of low surface tension

liquids. Since fluorochemical repellent finishes are normally applied by more conventional padding or spraying processes, repellency research has recently focused on Foam Finish Technology (FFT) systems on cotton fabrics (Turner, 1980, Wadsworth et al., 1983b, and Brown and Bryant, 1983). Other works have been published on cotton/polyester blend fabric (Namboodri and Duke, 1979). However, very little is published on fluorochemical repellent finishing of nonwoven fabrics especially low wet pickup finishing of nonwoven fabrics.

1.3.2 Low Wet Pickup Technique

Very little has been published on repellent finishing of nonwoven fabrics, especially polypropylene spunbonded fabrics and melt blown/spunbonded laminates (Strickler, 1984). There are two finishing techniques that have received a good deal of emphasis for low wet pickup applications: (1) the Foam Finish Technology, and (2) the Kiss Roll Technique. Before explaining these techniques, a review of the advantages of low wet pickup finishing methods is in order. Frank Clifford (1979) has identified several advantages of the low wet pickup technique:

- It brings greater savings in the energy needed for drying.
- It reduces and possibly eliminates migration during drying.
- It makes more efficient use of chemicals.
- Fabrics treated by the low wet pickup techniques can be rolled up without drying and stored quickly, and can be dried days later.

1.3.2.1 Foam finishing technology (FFT). This research does not directly relate to the theory and production of foam; however, articles by Turner (1980), Baker (1981), Bikerman (1965), and Bryant and Walter (1979) provide a more detailed treatment of the subject. Foam finishing technology involves a uniform application of a foamed finish to a substrate. One primary advantage of foam is that it uses air instead of water as the main diluent. This can be obtained by combining adequate foaming agents into a concentrated finish preparation and mechanically agitating the mixture. The use of less water means greater energy savings needed for drying. Little capital cost is needed to change conventional continuous finishing lines into foam application ranges. The only needed alterations are the installation of a mechanical foamer plus a method for spreading the foam uniformity onto the textiles.

A main consideration of the FFT system is its foam density. The FFT must maintain a semi-stable foam as opposed to a stable foam which may have the consistency of shaving cream. For textile use, foam density is usually under 0.05 g/cc, ranging from 0.01 to 0.3 g/cc. Proper foam density must be maintained in order to achieve uniform application. According to Bryant (1984), adjustments must be made to achieve positive pressure in applying an even coating of foam to the fabric. Altering foam density during a run leads to a temporary change in the rate of foam delivery to the fabric which can affect uniformity of application. It is important that the material absorbs the finish evenly or nonuniform wetting occurs.

Ruptured foam bubbles wet the substrate as the surface of the substrate absorbs moisture from the foam. The liquid is either absorbed by the fibers, or it is transported by capillary attraction into the small spaces between fibers. Surface fibers touching the foam hold a higher concentration of the active chemical than within the fibers. It is difficult to achieve even distributions of active chemicals on thicker substrates. Hence, the construction and composition of the fabric, and the end use affect the wetting rate and degree of penetration that is desired.

Finally, the absorption rate is another important consideration of the FFT system since it is essential to achieve an effective, uniform finish application. Uniform distribution of chemicals is achieved by the dual effects of rate of application of liquor over the fiber's surface and the absorption rate of the fibers (Bryant, April 1984). The faster the fabric speed, the higher the absorbancy percentage because at greater shear stress the foam breaks at the fabric/foam interface. Therefore, increased fabric speed has an effect on shearing of semistable foam and increases the absorption rate of the fabric.

1.3.2.2 Kiss roll technique. The kiss roll technique is another low wet pickup method involving the application of more concentrated chemicals. While the fabric travels over the top of the smooth steel roll, the bottom of this rotating roll picks up a film of finish liquor from the trough situated below it. As it rotates to the top position, the film of liquid that was picked up by the roll is transferred to the fabric in contact with it. Hence, the name, "kiss

roll," designates that the applicator roll "kisses" the chemical liquor onto the moving substrate. Basically, the advantages of the kiss roll technique are the same as those mentioned previously for low wet pickup method in general. One disadvantage, however, of the kiss roll technique is that it is sometimes difficult to achieve high solid add-on of chemicals. It is also difficult for chemicals to penetrate into the fabric thickness because surface fibers may tend to absorb unequal amounts of moisture and chemicals. However, wetting agent and film forming chemicals can minimize these problems.

This research project utilized the Triatex MA[®] process which is the most highly automated kiss roll applicator. In this process described in an article by Clifford (1979), the beta gage located in the front of the kiss roll measures the weight per unit area while the one located in the back measured the moisture content of the fabric after finishing. The moisture content measurement is governed by the kiss roll rotation speed and the fabric speed. The interconnecting controls are designed to guarantee uniform wet pickup and drying.

1.3.3 High Wet Pickup Technique

In the high wet pickup technique, the finish liquor is diluted with the addition of extra water. Therefore, high wet pickup levels on the fabrics range from 60-125% (low wet pickup levels under 50%). One finishing technique that dominates the high wet pickup field is the padding technique which is a conventional method of applying continuous finish. In the padding method, the fabric is dipped into the chemical mixture while the nip pressure squeezes the excess chemicals from the saturated fabric. While the nip pressure helps

control the wet pickup level, regulating the chemical concentration for different chemical add-ons to the fabrics is difficult. Wet pickup is affected by the dwell-time in the bath; therefore, fabric speed influences the amount of wet pickup at a designated nip pressure. Wet pickup levels also differ according to the varying thicknesses or absorbency characteristics across the fabric width. Moreover, it is difficult to lower the moisture content below the real absorbency level of the treated material. Nevertheless, the padding method has several advantages:

- It gives a more uniform penetration of finish because the fabric is first soaked and then it is squeezed.
- It can allow larger inaccuracies and errors in procedure.
- The padding operation will continue as long as it is provided with a chemical mixture.
- Since low wet pickup techniques are just going into the production phases (especially with nonwovens), padding methods may provide better finishing results until the low wet pickup technique can be refined for the particular nonwoven.

There are two main disadvantages of the padding method. First, it requires more energy to remove water from the treated fabric. To alleviate this problem, a pad vacuum can be installed to eliminate pre-dryers and to reduce energy consumption. Second, when the water leaves the treated fabric, the chemicals also migrate to the surface. This may not always be a disadvantage, however, because it has been indicated that the migration of fluorochemicals to the fabric surface may actually improve the repellency properties (Wadsworth, 1983b).

There are several problems concerning uneven finish associated with the padding method. For instance, the relatively high level of liquid in the fabrics causes contamination of rolls, cans, and all the equipment below the range of the pad. Unwanted chemicals in the fabric can also contaminate the bath since the fabric may choose to absorb some chemicals in the bath as opposed to others. These unwanted chemicals alter the quality of the bath and its concentration. The bath, however, continually may be refilled to overpower contamination and exhaustion. Foam-in-the pad bath is another problem which results in an uneven finish but can be alleviated by using defoaming agents and other chemical additives.

CHAPTER II

REVIEW OF LITERATURE

Several researchers have conducted studies on areas related to nonwoven protective materials. Much of the research focuses on determining barrier properties of the following fabrics: (1) Teflon[®], (2) Tyvek[®], (3) spunbonded olefins, (4) laminates of paper over polypropylene scrim, and (5) spunbonded polypropylene and melt blown laminates.

2.1 TEFLON

One area of research has focused on Teflon as a good protective membrane with excellent barrier properties. Therefore, it would be advantageous if a "Teflon" type surface could be obtained after fluorochemical treatment of the melt blown/spunbonded laminates. One research group, Weeks and McLeod (1980), conducted a study with Teflon, polyethylene (PE)-coated Tyvek and other protective material membranes to observe their barrier properties against liquid halogenated ethanes and a polychlorinated biphenyl. Permeation was determined by the breakthrough time. Results indicated that the Teflon offers the best barrier properties, but it is capable of crumpling during actual end-use.

2.2 TYVEK

Several studies have been done to test the performance characteristics of Tyvek, a spunbonded polyolefin, against hazardous

chemicals. Tyvek consists of fine continuous-interconnected polyethylene filaments arranged in a thin web which can be thermally bonded to film, fabric, and paper. Because of its unmatched protective barrier property, Tyvek is most advantageous for industrial protective attire.

Arthur D. Little, Inc. administered a permeation test program to resolve which type of Tyvek was most effective for protection against selected chemical hazards. The firm selected Arthur D. Schwope to direct these highly sophisticated tests. Breakthrough time and permeation rates were measured for all liquids. The breakthrough time is the time from which the chemical first contacts the material until the chemical is detected on the opposite side of the material. The penetration rate is the rate at which chemicals migrate through the material following the breakthrough time. Three varieties of Tyvek were chosen for these studies: (1) the uncoated Tyvek (1422A) form, (2) this identical style coated with 1.25 mils of polyethylene (PE) film, and (3) Tyvek laminated to 1.3 mils. of Saranex film.

In one study by Schwope (1984a) Tyvek was evaluated for its barrier properties to methyl parathion (MP), a pesticide. Both Tyvek and PE coated Tyvek showed faster breakthrough times than Saranex coated Tyvek, but their penetration rates were not similar. He suggested that the difference in penetration rates are a result of the fabric's nonuniformity which could be the same explanation for the variance in the air penetration rates among Tyvek samples. Methyl parathion penetration was higher for the Tyvek specimen with the higher air penetration rate; lower MP penetration was associated with

the specimen having lower air penetration rate. Saranex coated Tyvek had a very slow breakthrough time compared to the PE coated Tyvek. Hence, Saranex coated Tyvek was considered a better candidate for protection against methyl parathion.

Meanwhile his study on Tyvek and Tyvek composites were tested as barriers against Aroclor[®] 1254, a polychlorinated biphenyl (PCB). As before, Saranex coated Tyvek provided a significantly higher resistance to permeation than polyethylene coated Tyvek. The results indicate that Tyvek laminated with Saranex would be the best choice of protection against Aroclor 1254 and its common diluting substance. Then his other study on Tyvek and Tyvek composites were tested as barriers against toluene, cresols and o-Toluidine Schwope (1984c). Toluene, a chemical that is a starting material for a wide range of organic chemicals and many intermediates and final products, and o-toluidine, an important dye intermediate, are suspected carcinogens. Cresols are used in the manufacturing of agricultural chemicals. With a breakthrough time of two hours, Tyvek laminated with Saranex provided a better barrier for cresols and o-Toluidine compared with polyethylene coated Tyvek with a breakthrough time of 40-60 minutes for cresols and less than five minutes for o-Toluidine. For both Tyvek composites the breakthrough time was less than five minutes for toluene.

Branson, DeJonge and Munson (1986) also performed an important research project with Tyvek and Gore-Tex[®] involving thermal comfort. In an earlier study Gore-Tex showed valuable barrier properties to pesticide spray (Orlando, Branson, Ayers and Levitt, May 1981).

Similar skin temperatures were encountered by the subjects wearing Gore-Tex and those wearing 100% cotton chambray, and both physiological and perceptual measurements were in agreement. On the other hand, subjects wearing Tyvek experienced greater heat sensation and discomfort compared to those subjects wearing Gore-Tex and cotton chambray. Furthermore, this study demonstrated Gore-Tex would be ideal for protection and comfort, yet the costs may be too great for disposable apparel.

Nigg, Stamper and Queen (1986) studied the effect of dermal exposure, in which mix-loaders (persons who put pesticide in a spray apparatus for mixing) and applicators (persons who apply the pesticides) wore Tyvek disposable protective suits. An ungloved, normally-attired applicator wearing a disposable Tyvek protective suit had a 38% reduction of total dermal exposure, 27% by wearing gloves only, and 65% by wearing both. In the case of mix loaders, Tyvek suits reduced total dermal exposure by 40%. Hence, Tyvek suits worn by mix-loaders and applicators did help reduce total dermal exposure.

2.3 SPUNBONDED OLEFINS

Spunbonded olefins, other than Tyvek, also offer good possibilities for protective clothing. Staiff, Davis and Stevens did penetration studies (1981) with spunbonded olefins (SB0), white and yellow SB0 coated with PE, perforated SB0, and rubberized cotton. Swatches of the materials were subjected to spray applications of the pesticides parathion, methyl parathion, guthion and endosulfan.

It was found that white coated SBO and rubberized cotton demonstrated good protection against parathion in a test meant to be representative of splashes of pesticide concentrate on the worker's garment. To further explain the results of the parathion penetration study revealed that spunbonded olefin had the second best mean penetration score of 0.55 g or micro gram/cm² of parathion next to rubberized cotton with a mean penetration score of .067 g or micro gram/cm² of parathion.

2.4 PAPER OVER POLYPROPYLENE NET

Another area of research has focused on a laminate of paper over polypropylene net. This unusual disposable nonwoven material is actually a scrim of loose mesh of paper and polypropylene nonwoven material that has little cover, yet it is quite strong. Kavar, Gunther, Serat and Iwata (1978) did a study on the effects of dust and vapor penetration on this material. The goal of this experiment was to choose a protective material which minimizes the penetration of hazardous dust particles from foliage to workers' skin. Among all the materials tested, knitted fabrics permitted the greatest air flow varying from 67 to 176 cm³/cm²sec while woven fabrics permitted air flow of a low 18 to 49 cm³/cm²/sec. According to the authors, the addition of fluorochemical polymers to these fabrics reduced air flow by 14 to 24%. Knitted fabrics permitted dust penetrations from 87 to 96% while woven fabrics permitted only 0.3 to 5.8%.

The disposable nonwoven material in the study was made from paper and from paper over a polypropylene net. These nonwoven fabrics

permitted less than 0.5% dust penetration. Wearing test results from the first tests showed that the nonwoven coverall was as comfortable as the light weight cotton ones. The rate of vapor penetration through both nonwovens was about 4 to 5 times greater than compared with cotton woven fabric. Even though there was a high vapor penetration of both disposable nonwoven materials, they both meet the requirements of the Kawai's study; that is, there was minimum penetration of hazardous dust particles.

2.5 SPUNBONDED POLYPROPYLENE AND MELT BLOWN LAMINATES

Spunbonded/melt blown laminates are considered good candidates for protective clothing. These fabrics have relatively good barrier properties. One unpublished report by Oakland (1985) conducted at the University of North Carolina at Greensboro closely relates to this research project in that they evaluated commercial samples of fluorochemically-treated spunbonded melt blown/spunbonded (SMB) polypropylene laminates. In the Oakland study, laminates were furnished by a company specializing in nonwovens, whereas in this study, the MB/SB laminate was prepared by combining 0.8 oz/yd² melt blown polypropylene that was produced on the Exxon 20-inch melt blown pilot line at The University of Tennessee with a 1.6 oz/yd² experimental point bonded spunbonded fabric obtained from Du Pont. Also, the thermal bonding was performed on a smooth roll calender in the university laboratory which was donated by Surgikos, a Johnson and Johnson company. This study prepared and evaluated three layered commercial laminates of spunbonded/melt blown/spunbonded (SMS).

Moreover, in the Oakland study the fluorochemical finish and thermal bonding of the SMS laminate was applied in a commercial setting while the Scotchgard® treatment was in a laboratory setting; whereas in this study the laminates were treated with different fluorochemical finishing applications and thermally bonded in a laboratory setting.

In the Oakland study, aerosol penetration tests and air performance tests were performed on a spunlaced polyester and wood tissue composite, on spunbonded olefins, and on spunbonded/melt blown/spunbonded (SMS) laminates. Fabrics were subjected to three aerosol spray solutions that simulated pesticide spraying media: (1) tap water, (2) a water-based solution, and (3) oil-based solution. The test for aerosol spray permeability was based on an ASTM method for aerosol spray on metals.

The air permeability results showed that the spunlaced composites of polyester and wood pulp were most similar to those of the woven fabrics (the control group) and ranked high in water vapor permeability. The spunbonded/melt blown/spunbonded fabrics showed low or no air permeability. However, the perforated spunbonded fabric had a slightly higher air rate, yet low enough to be uncomfortable during work conditions.

In general, the fluorochemically finished nonwoven fabrics samples, either commercially or laboratory treated, passed the aerosol spray tests. The commercially finished spunlaced fabrics passed all the spray tests. With the exception of perforated spunbonded fabrics, all the other laboratory finished ones passed the three spray tests. With only two layers of the finished fabrics, the perforated

spunbonded fabrics passed the water-based spray tests. Scotchgard treated SMS in both gray and white passed all three aerosol spray tests. In addition, Oakland noted that the spunlaced fabrics also were stronger and more "clothlike" than other spunbonded or SMS fabrics tested.

Chapter III

METHODOLOGY

The methods used in conducting experimental research to evaluate three finishing techniques applied to the spunbonded fabrics and melt blown/spunbonded laminates included the following: describing the nonwoven materials used in this experiment; describing finishing and thermal bonding techniques used in this experiment; presenting the experimental design of this study; identifying the six different repellency and barrier tests chosen for this study, and finally, carrying out approximate statistical analysis of this study.

3.1 MATERIALS

This study involved the following materials (1) a polypropylene point bonded spunbonded fabric, (2) a polypropylene melt blown fabric, and (3) a melt blown/spunbonded laminate (MB/SB).

3.1.1 Polypropylene Point Bonded Spunbonded Fabric

The experimental polypropylene point bonded spunbonded fabric was made by Du Pont. It had a weight of 1.60 oz/yd^2 (53.8 g/m^2). It has well-spaced bond points which prevents the fabric from becoming too stiff and inflexible. Both sides of this fabric have noticeably different surface appearances. One side had a darker shade of blue with deeper embossing resulting in a rougher surface. The other side had a slightly lighter shade of blue with a less pronounced embossing resulting in a smoother surface.

3.1.2 Polypropylene Melt Blown Fabric

A second fabric used in this study was a polypropylene melt blown fabric which was made on the 20-inch melt blown pilot line in the Textile Processing Laboratory at The University of Tennessee, Knoxville. It had a weight of 0.80 oz/yd^2 (24.2 g/m^2). This fabric possesses ultrafine fibers which makes it light weight compared to the spunbonded fabric weight and breathable, and a good barrier for use in protective apparel.

3.1.3 Melt Blown/Spunbonded Laminate

The experimental point bonded spunbonded polypropylene fabric (obtained from Du Pont) and the melt blown fabric (produced at the university) were layered together with the melt blown web against the more deeply embossed side of the spunbonded fabric to form the third type of fabric used in this study. This laminate had a weight of 2.37 oz/yd^2 (80.58 g/m^2). In the processing laboratory at the university, two techniques for thermally bonding the melt blown/spunbonded laminate were developed. In one technique, the point bonded spunbonded polypropylene fabric was thermally bonded to the melt blown polypropylene fabric (Laminate I Sample Set) prior to fluorochemical (FC) finishing. In the other, the melt blown and spunbonded components were fluorochemically finished separately before thermal bonding (Laminate II Sample Set). One eight yard (7.3 m) composite was made for each fluorochemical application using FFT, kiss roll and padding methods. Both laminate techniques resulted in new fabrics with a smooth, but relatively firm hand.

3.2 FINISHING AND BONDING TECHNOLOGIES

This study focused on finishing and thermal bonding technologies commonly used in the textile industry: (1) foam finish technology (FFT), (2) kiss roll technique, (3) padding method, and (4) thermal bonding. Finish formulations for the FFT, kiss roll and padding methods are given in Table II. Sources of chemical finishing agents are given in Table III. The fabric samples fluorochemically treated in this study were subjected to a cure temperature of 285°F (176°C) and a cure time of three minutes. The cure temperature was chosen because a temperature higher than 285.0°F caused notable shrinkage.

3.2.1 Foam Finishing Technology (FFT)

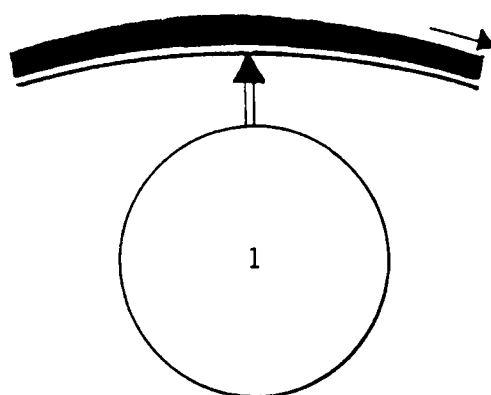
The Foam Finishing Technology (FFT) Laboratory Unit at Gaston County Dyeing Machine Corporation in Stanley, North Carolina was used in this study. A foamer continually mixes compressed air and the finish mixture, containing a nonrewetting foaming agent, to create a homogeneous foam. Foam is delivered to the applicators with a slit width of 1/8 inch across 18 inches of the 20-inch wide fabric. The fabric speed was 10 yds/min. When the semi-stable foam contacts the substrate, the bubbles rupture and the liquor is absorbed to varying degrees depending on fabric processing conditions. To achieve a desired percentage of solids add-on as the fabric moves across the applicator, the liquor flow rate and foam density was monitored. As shown in Figure 1, it was possible to apply foamed finish on one side of the fabric only or on both sides in one pass through the machine.

Table II. Fluorochemical Formulations

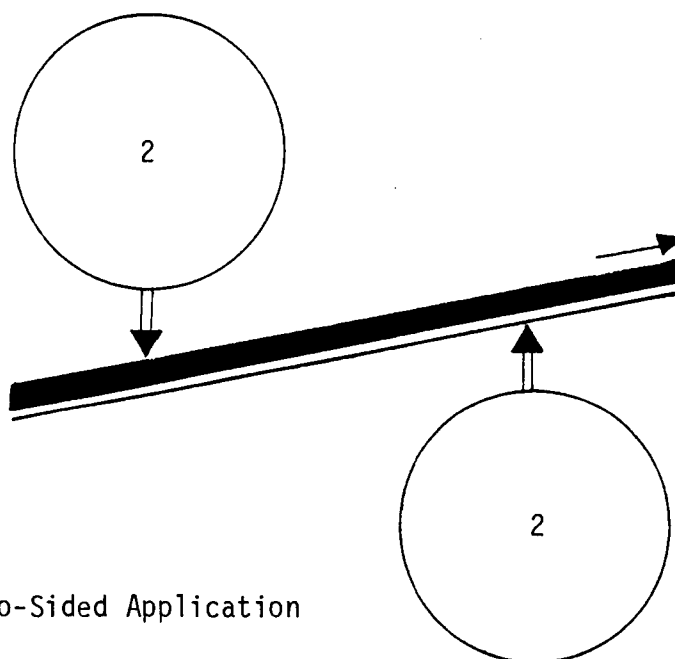
<u>FFT Application (Planned Wet Pickup of 50%)</u>		
<u>Agent</u>	<u>g/100</u>	<u>g/10,000</u>
Zepel [®] RN	6.0	600.0
Extender	12.0	1,200.0
Standapon [®] 4377	0.5	50.0
Water	<u>81.5</u>	<u>8,150.0</u>
	100.0g	10,000.0g
<u>Kiss Roll Application (Planned Wet Pickup of 50%)</u>		
<u>Agent</u>	<u>g/100</u>	<u>g/10,000</u>
Zepel [®] RN	6.23	623.0
Extender	12.47	1,247.0
Siligen [®] MA	0.20	20.0
Water	<u>81.10</u>	<u>8,110.0</u>
	100.00g	10,000.0g
<u>Padding Application (Planned Wet Pickup of 100%)</u>		
<u>Agent</u>	<u>g/100</u>	<u>g/10,000</u>
Zepel [®] RN	3.0	300.0
Extender	6.0	600.0
Water	<u>91.0</u>	<u>9,100.0</u>
	100.00g	10,000.0g

Table III. Sources of Commercial Finishing Agents

Agent	Description	Supplier
Zepel RN	Water, oil and stain resistant finish; aqueous dispersion of a fluoropolymer	E. I. du Pont de Nemours & Co.
Extender	Water repellent used with fluorochemicals	E. I. du Pont de Nemours & Co.
Standapon 4377	Nonionic foaming agent	Henkel Corporation
Siligen MA	Wetting and film forming agent	BASF Corporation



One-Sided Application



Two-Sided Application

Figure 1. One and two-sided FFT application.

Source: Larry C. Wadsworth, "Foam Application of Durable Press and Fluorochemical Finishes to Cotton Fabrics," Textile Chemist and Colorist, Vol. 15, No. 12, December 1983, p. 241/27.

3.2.2 Kiss Roll Technique

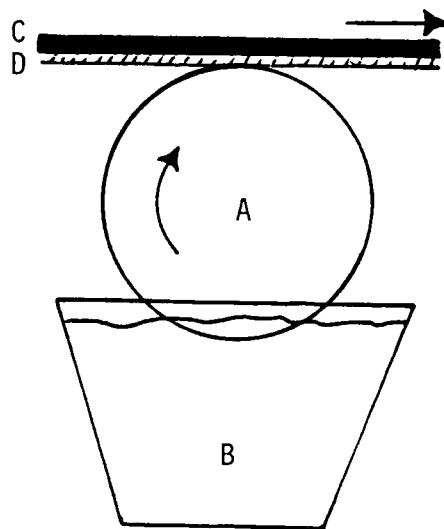
The Triatex MA laboratory kiss roll applicator at Gaston County was also used in this study. As shown in Figure 2, the finishing liquid is contained in a small trough designed for easy draining. The smooth steel roll is situated in the trough so that the bottom of the roll picks up a film of finish liquor as it rotates. The finish was then transferred to the fabric which runs across the top of the roll. In this technique a beta gauge located downstream monitors the amount of liquid pickup so that the roll can be speeded up or slowed down to maintain the proper pickup.

3.2.3 Padding Method

A 24-inch laboratory padder at Gaston County was used in this study. The padder, Figure 3, consisted of a trough containing the finishing liquor into which the fabric was dipped. Two rubber squeeze rolls situated above the trough removes the excess finish mixture from the fabric and the nip pressure was adjusted to achieve the required wet pickup.

3.2.4 Thermal (Area) Bonding Technique

A Morrison Calender (donated by Surgikos) in the Textile Processing Laboratory at The University of Tennessee, Knoxville was used in this study. This unit has one rubber back up roll which is located between two Teflon coated smooth steel rolls. Heated oil travels through the cores of the steel rolls. The laminates were only passed between the bottom steel roll and the rubber back-up roll of the three roll calender as shown in Figure 4.



- A. Rotating Steel Roll
- B. Treatment Bath
- C. Spunbond Side of MB/SB Laminate
- D. Melt Blown Fabric Side

Figure 2. Simplified version of kiss roll applying unit.

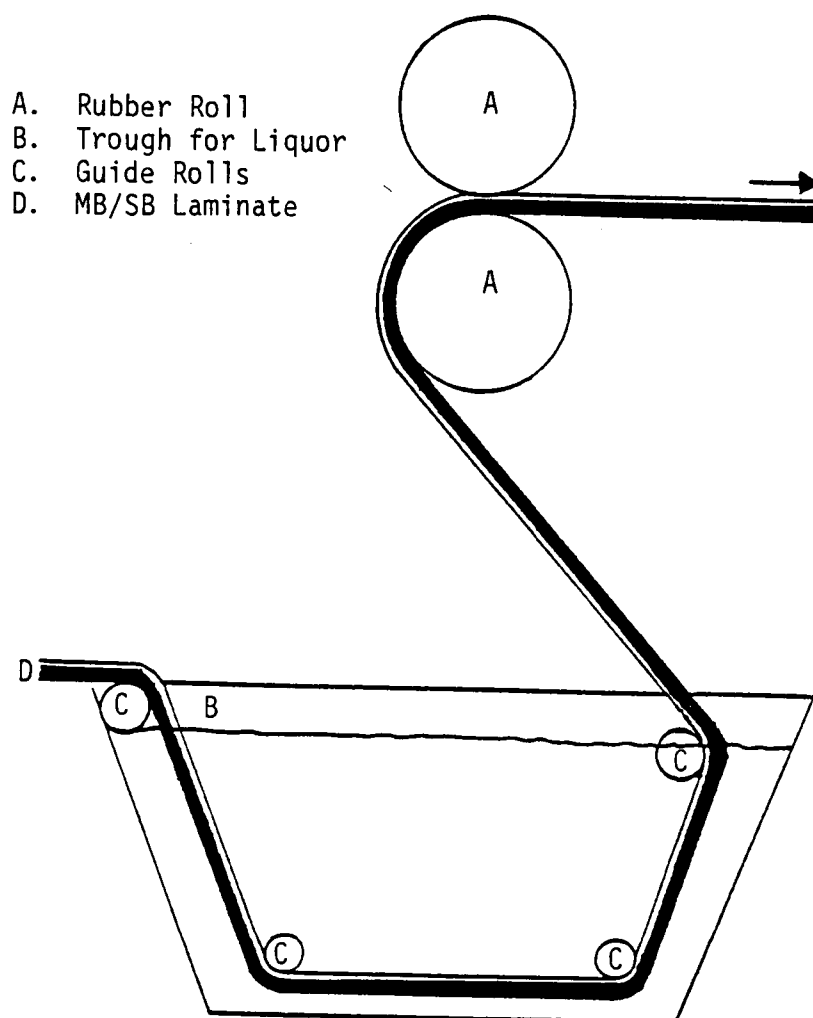
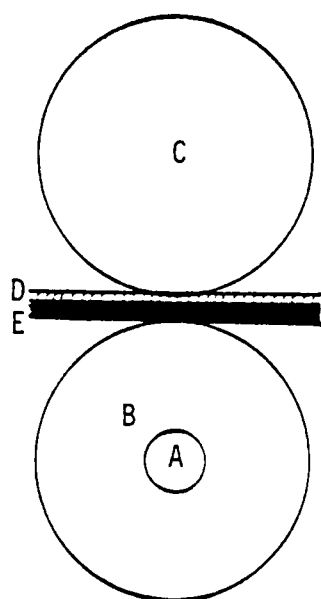


Figure 3. Schematic illustration of Padding process.



- A. Oil-Heated Core
- B. Teflon Coated Steel Roll
- C. Rubber Roll
- D. Melt Blown Fabric
- E. Spunbonded Fabric

Figure 4. Schematic illustration of thermal bonding calender.

3.3 EXPERIMENTAL DESIGN

Repellent treated spunbonded fabrics, melt blown/spunbonded (MB/SB) laminates, as well as all control fabrics were evaluated for repellency and barrier properties. The control fabrics included an untreated melt blown fabric, an untreated spunbonded fabric, an untreated unbonded MS/SB laminate and an untreated thermally bonded MB/SB laminate. The experimental design for the thermal bonding sequence of Laminate Set I (thermally bonded and then FC finished) and Laminate Set II (FC finished and then thermally bonded), as well as, for the repellent finishing of the spunbonded fabric is shown in Figure 5.

3.3.1 Preparation of Laminate I Sample Sets

The first part of this experiment involved thermally bonding the MB/SB samples before finishing them with the three types of fluorochemical applications, henceforth known as Laminate I Sample Sets (see Figure 5). With Laminate Set I, bonding of the melt blown web to the spunbonded fabric was performed by passing the two between the bottom oil heated steel roll and the rubber backup roll of the calender. Throughout the thermal (area) bonding process, the melt blown side faced the rubber roll to avoid over heating and melting of the melt blown web. The fabric speed was 10 ft/min. Several trials were made to determine the appropriate steel roll temperature and nip pressure to result in good adhesion without imparting notable stiffness or film-like qualities to the laminate. Under optimum conditions, the melt blown fabric did not peel off easily nor did it

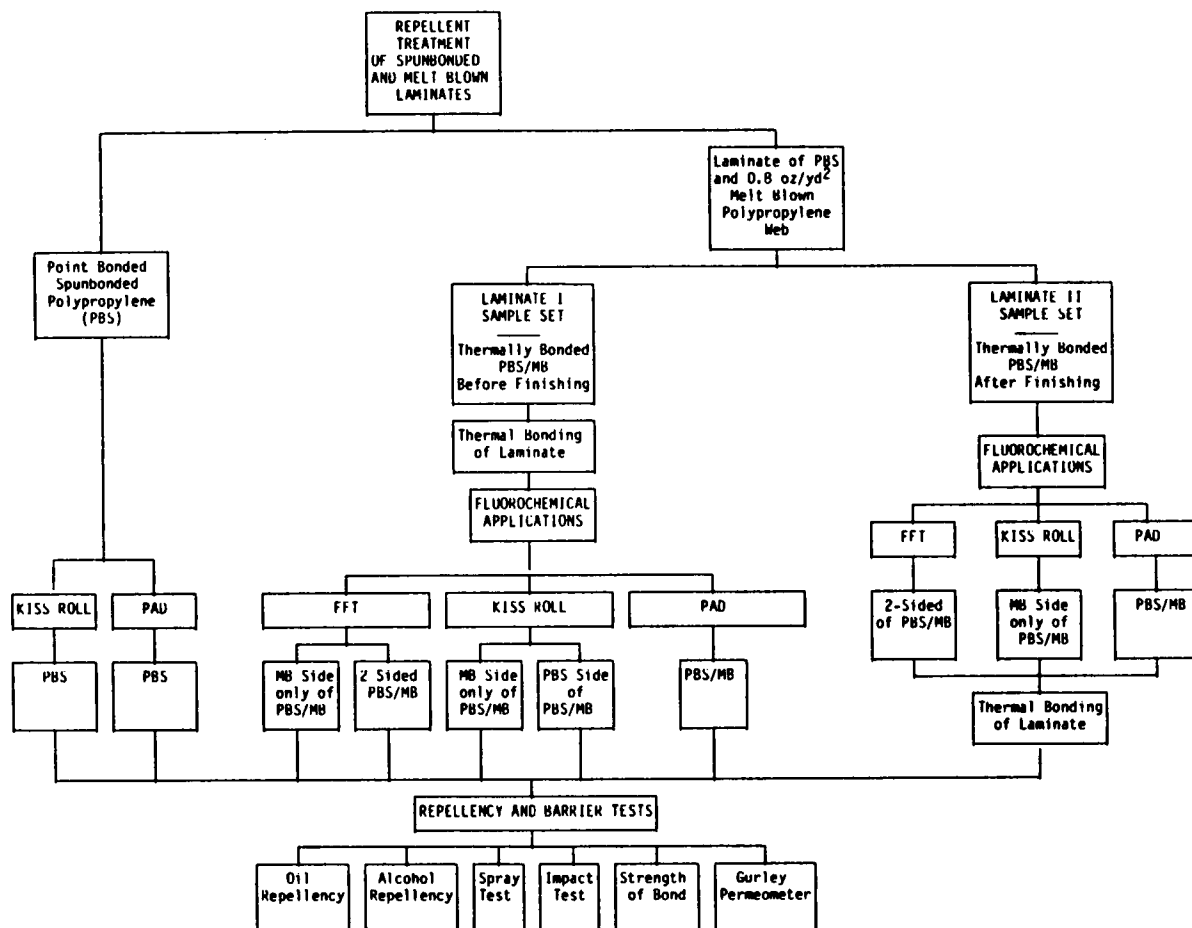


Figure 5. Experimental design for polypropylene (PP) point bonded spunbonded/melt blown composites (PBS/MB) that was thermally bonded before or after finishing.

completely fuse together, but it maintained a fabric-like hand. Thermal bonding conditions for MB/SB laminates, before fluorochemical applications, are given in Table IV.

After bonding, the Laminate I samples were finished by FFT, kiss roll, and padding techniques. In the FFT method, the bottom applicator was used for one sided application, whereas both the top and bottom applicators were used for two sided applications in which both sides of the laminate (Samples F-1 and F-2, Table V) were foam treated. Liquor flow rate and fabric speeds were carefully monitored to ensure desired wet pickup. The fabric speed was 9.14 meters/min. (10 yards/min.). Fabrics were wound on cardboard tubes at the winder of the FFT unit. Then the samples passed through the tenter oven for curing.

In the kiss roll technique, one sample of Laminate I was treated on the spunbonded side (K50, Table VI), then the other sample was treated on the melt blown side (K20, Table VI). The melt blown fabric has greater surface area because less fluorochemical finish is required to completely cover the greater number of finer fibers. The Laminate I Sample Set was treated as the fabric ran across the top of the smooth steel roll which picked up a film of finish as it rotated. Then, the two samples were passed through the tenter frame for curing.

In the padding process, each eight yard sample of Laminate I was dipped in the trough and then put through the nip to squeeze out excess chemicals. By utilizing low padding pressures and multiple paddings, the Laminate I fabric (P-89, Table VII) was able to increase the wet pickup levels to the planned level of 100%.

Table IV. Thermal Bonding Conditions¹Laminate Set IA²

Pressure - 20 PSI (369 PLI)³
 Oil Temperature - 270°F
 Steel Roll Surface Temperature - 230°F

Laminate Set IB²

Pressure - 35 PSI (645 PLI)³
 Oil Temperature - 282°F
 Steel Roll Surface Temperature - 233°F

Laminate Set IIA⁴

Pressure - 70 PSI (1290 PLI)³
 Oil Temperature - 325°F
 Steel Roll Surface Temperature - 264°F

Laminate Set IIB⁴

Pressure - 80 PSI (1474 PLI)³
 Oil Temperature - 340°F
 Steel Roll Surface Temperature - 280°F

¹In all trials, the melt blown side was against the rubber roll and the spunbonded side was against the steel roll.

²Laminates were thermally bonded before finishing; were run through the nip once.

³Nip pressure in "psig" is the pressure on the hydraulic cylinders applying force through the mechanical system to the nip between the steel and rubber rolls, and the actual nip force is expressed in pounds per linear inch (PLI).

⁴Laminates were thermally bonded after finishing; were bonded at higher temperature and pressure and were run through the nip twice.

Table V. Thermal Bonding and FFT Applications of Melt Blown/Spunbonded (MB/SB) Laminates.

Sample No.	Sample Description	Bonding Sequence		Bonding Conditions	Fluorochemical Application Conditions	Wet Pickup Percentage
		Before Finishing	After Finishing			
F-1	FFT treated MB/SB laminate	X		35 PSI (645 PLI) nip ^a 282°F oil Temp	Treated on both sides	10.0
F-2	FFT treated MB/SB laminate	X		35 PSI (645 PLI) nip 282°F oil Temp	Treated on melt blown side only. Set at 50% WPU but actually 7.9% WPU.	7.9
F-3	FFT treated MB/SB laminate		X	80 PSI (1474 PLI) nip 340°F oil Temp	Treated on both sides. Set at 50% but actually 40-60% WPU range.	40.0-60.0

^aNip pressure of 20 pounds per sq. inch (PSI) corresponded to a nip loading force of 369 pounds per linear inch (PLI).

Table VI. Thermal Bonding and Kiss Roll Applications of Melt blown/Spunbonded (MB/SB) Laminates.

Sample No.	Sample Description	Bonding Sequence		Bonding Conditions	Fluorochemical Application Conditions	Wet Pickup Percentage
		Before Finishing	After Finishing			
K 50	Kiss roll treated MB/SB laminate	X		20 PSI (369 PLI) ^a 270°F Oil Temp.	Treated on spun-bonded side	50.0
K 20	Kiss roll treated MB/SB laminate	X		20 PSI (369 PLI) 270°F Oil Temp.	Treated on melt blown side	20.0
K-1	Kiss roll treated MB/SB laminate		X	70 PSI (1290 PLI) 325°F Oil Temp.	Treated on melt blown side	51.0
K-2	Kiss roll treated MB/SB laminate		X	70 PSI (1290 PLI) 325°F Oil Temp.	Treated on melt blown side and squeezed twice through padding nip to 41.0% WPU originally 54.6% WPU	41.0

^aNip pressure of 20 pounds per sq. inch (PSI) correspond to a nip loading force of 369 pounds per linear inch (PLI).

Table VII. Thermal Bonding and Padding Applications of Melt Blown/spunbonded (MB/SB) Laminates.

Sample No.	Sample Description	Bonding Sequence Before Finishing	After Finishing	Bonding Conditions	Padding Pressures	Wet Pickup Percentage
P 89	Padded MB/SB Laminate	X		20 PSI (369 PLI) ^a 270°F Oil Temp.	15 PSI 4 dips 4 nips	89.0
P2	Padded MB/SB Laminate		X	70 PSI (1290 PLI) 325°F Oil Temp. Thermally Bonded Twice	80 PSI padded twice	123.9
P3	Padded MB/SB Laminate		X	70 PSI (1290 PLI)	80 PSI 1 dip 3 nips	127.7

^aSee Footnote "a," Table V.

3.3.2 Preparation of Laminate II Sample Sets

In the second part of this experiment the melt blown and spunbonded components were fluorochemically treated separately by FFT, kiss roll and padding application techniques before thermal (area) bonding. Henceforth, these were known as Laminate II Sample Sets (see Figure 5). The only sample of Laminate II which was treated by FFT application was finished on both sides (F-3, Table V). However, in the kiss roll method, the Laminate Set II samples, (K-1 and K-2 in Table VI) were treated only on the melt blown side. Only sample K-2 was subjected to two nips through the padder to determine if squeezing through the padder nip would improve penetration of fluorochemical throughout the laminate. In the padding process, samples P2 and P3 (Table VII) were padded several times in efforts to reduce the wet pickup to the desired level of 100%. Both samples utilized padding pressures of 80 PSI.

As mentioned, these sample sets of Laminate II were thermally bonded after finishing. With the Laminate II samples higher temperatures and nip pressures were required because the fluorochemicals reduced the surface energy which made the adhesion between the layers more difficult. Thermal bonding conditions for Laminate II Sample Sets IIA and IIB are given in Table IV.

3.3.3 Finishing of Spunbonded Fabric

The repellent finishing of the spunbonded fabric involved finishing by the kiss roll and padding methods. Two identical sample rolls of spunbonded fabric (K53 and K48-6, Table VIII) were treated on

Table VIII. Thermal Bonding, (and) Padding and Kiss Roll Applications of Spunbonded Fabrics Alone.

Sample No.	Sample Description	Fluorochemical Application Conditions	Wet Pickup Percentage
K 53	Kiss roll treated Spunbonded fabric	Treated on D side ^a	53.0
K 40	Kiss roll treated Spunbonded fabric	Treated on L side ^b	40.0
K 48-6	Kiss roll treated Spunbonded fabric	Treated on D side	48.6-50.0
K 40-6	Kiss roll treated Spunbonded fabric	Treated on L side	40.6
P 96	Padded Spunbonded fabric	70 PSI 1 Dip 3 Nips	96.3

^aTreated on deeper embossed side.

^bTreated on less embossed side.

the more embossed side, and two other sample rolls (k40 and K40.6, Table VIII) were treated on the less embossed side. Thus, both sides of the spunbonded fabric were treated because it was not known if the depth of the embossing would affect wet pickup levels.

In the padding method, the spunbonded fabric sample was dipped in the trough once and then put through the nip three times in order to reduce the wet pickup to approximately 100%. The padding pressure for this sample was 70 PSI. The padding process conditions for sample P-96 are given in Table VIII.

3.3.4 Determination of Wet Pickup Percentages

Wet pickup is the amount of finish liquor that is absorbed by the fabric. Wet pickup was determined immediately after each finishing method as soon as the wet fluorochemically treated piece of fabric was cut off and weighed. Afterwards, the finish was washed out and the fabric was dried and conditioned. The fabric was weighed again to determine wet pickup percentage (WPU%):

$$\text{WPU\%} = \frac{\text{Weight of Finished Fabric} - \text{Weight of Non-finished Fabric}}{\text{Weight of Non-finished Fabric}} \times 100$$

3.4 TESTING METHODS

Standard INDA and AATCC tests were performed to determine the repellency and barrier properties of the polypropylene spunbonded fabrics, the MB/SB fabrics and all the control samples. It is important to record here that all the fabrics tested in this study were subjected to standard textile testing conditions: $65\% \pm 2\%$ relative humidity and $70^{\circ} \pm 2^{\circ}\text{F}$.

Six tests were selected to determine the fabric characteristics for: (1) water repellency, (2) water impact penetration, (3) oil repellency, (4) alcohol holdout, (5) Gurley permeometer air permeability, and (6) tensile strength of laminate bonding. Of the six tests, only four (water repellency, water impact penetration, oil repellency, and alcohol holdout) were performed on all samples. The treated sides of the laminates were subjected to the repellency tests. The Gurley permeometer test was performed on four control samples and on the Laminate I and II specimens. The Laminates I and II Sample Sets, the unfinished bonded control fabric and a commercial SMS laminate were evaluated for the ASTM Strength of Bond Test.

3.4.1 Water Repellency Test

The AATCC Test Method 22-1980, "Spray Test," was the procedure used for the water repellency test (AATCC, 1984). In this procedure the sample fabric was held tightly on a metal hoop positioned at a 45° angle and sprayed with 250 ml of distilled water. The spray nozzle was positioned six inches above the center of the fabric specimen placed within the metal hoop. After the fabric was sprayed, it was

rated by comparing it with pictures on a standard chart. Depending on the amount of samples available, three to five specimens (7 x 7-in.) from each sample were evaluated.

3.4.2 Impact Penetration Test

The AATCC Test Method 42-1980, "Impact Penetration Test" was the procedure used to determine the barrier effectiveness against penetration (AATCC, 1984). In the water impact test the fabric specimen was tightly mounted on a 45° surface and backed with a conditioned pre-weighted blotter. The fabric was sprayed with 500 ml of distilled water from a height of two feet. The blotter was removed and weighed to calculate the increase in its weight. Three to five specimens (13 x 7-in.) from each sample were evaluated.

3.4.3 Oil Repellency Test

The AATCC Test Method 118-1983, "Hydrocarbon Resistance Test," was the procedure used for the oil repellency test (AATCC, 1984). The oil repellency test was chosen for this study because oil based pesticides are encountered in agricultural applications and low surface tension oils are also present in operating rooms.

In the oil repellency test drops of a series of hydrocarbons of different surface tensions ranging from 0 to 8 (8 having the lowest surface tension) were placed on the test fabric. Any evidence of wetting or wicking was observed for 30 seconds. The ratings were determined by the highest number in hydrocarbon series which did not show signs of wetting the fabric.

3.4.4 Alcohol Holdout Test

The INDA Standard-Test Method 80.9-74 (R82) was the procedure used for the alcohol repellency test (INDA, 1985). The alcohol repellency test was chosen for the study because alcohols are used in the hospital operating rooms. In the alcohol repellency test, drops of a selected series of water/ethanol solutions ranging from 0-10 (10 being 100% ethanol) were placed on the test fabric and any evidence of penetration was observed for five minutes. The alcohol ratings were determined by the highest number in the series of water/ethanol solutions which did not penetrate or wick through the nonwoven fabric.

3.4.5 Gurley Permeometer Test

The ASTM Test Method D737-75, "Air Permeability of Textile Fabric," was chosen to indicate whether these composite samples would be breathable enough for use in the operating rooms and/or pesticide applications (ASTM, 1984). The Model TY 1253 1971 Gurley Permeometer was used. In this test, the adjustable needle valve allowed the differential pressure of each specimen to be easily determined. Variations in the standard 0.5 inch pressure can be easily observed and corrected by the expanded scale gauge. Hence, these control features can better assure a higher degree of accuracy. Three to five 5 x 5 inch specimens were evaluated per sample.

3.4.6 Strength of Laminate Bond Test

Under the ASTM Test Method D 2724-79, Section 13, "Strength of Bond," was the procedure used to determine the bond strength of the laminates (ASTM, 1984). These samples were not subjected to

laundering as specified in the preparation procedure for this test. Since the quantity of laminated fabrics was limited, five 2 x 6 inch specimens were evaluated. A 100 gram load was used to calibrate the Instron. The Instron measured the bond strength and graphically recorded them. The average of the five lowest and five highest peak loads of resistance were taken to help determine the bond strength in milli-Newtons (mN).

3.5 STATISTICAL ANALYSIS

The Student-Newman-Keuls (SNK) test was used to compare the means within each test method (impact penetration test, Gurley permeometer and strength of bond test). This enables each fabric to undergo all possible comparisons. The means values are ranked from largest to smallest. The null hypothesis states that the means are the same. The alternative hypothesis states that there is a significant difference between the means, the significance level was 95%.

The oil, water and alcohol repellency tests (discrete data) were examined by Fisher's Exact Test (FET) which uses 2 x 2 contingency tables. The null hypothesis would state that the expected fabric response are equal between the fabrics selected. The alternative hypothesis is that one fabric response is greater than the other (one tail test). The significance level was 95%.

CHAPTER IV

RESULTS AND DISCUSSION

In this section, the results will be discussed and interpreted regarding the following tests: (1) water repellency test results, (2) impact penetration test results (3) oil and alcohol repellency test results, (4) Gurley permeometer test results, and (5) strength of laminate bond test results.

4.1 WATER REPELLENCY TEST RESULTS

The results of the water repellency (spray) test are discussed in reference to the process considerations: (1) effects of bonding sequence, and (2) effects of wet pickup variations in different finishing methods.

4.1.1 Effects of Bonding Sequence

Even though the thermally bonded control fabric (sample C-1, Table IX) was not fluorochemically (FC) finished, it exhibited the maximum water spray ratings of 100. The unbonded laminated control fabric (sample C-2, Table IX) had a slightly lower spray rating of 94.0 which is still considered excellent. On the other hand, the unfinished melt blown (sample C-MB) and spunbonded (sample C-SB) control fabrics resulted in a lower average spray rating of 76.0 and 78.0, respectively. The Fisher's Exact Test (FET) supported these findings at the 0.05 level. For example, when sample C-1 with an excellent spray rating of 100.0 was compared with the unfinished

Table IX. Repellency and Barrier Properties of Unfinished Control Laminates and the Unfinished Spunbonded and Melt Blown Control Fabrics.

Sample No.	Sample Description	Bonding Conditions	Water Spray Ratings (0-100)	Water Impact Penetration (gram)	Oil Repellency Rating (0-8) ^d	Alcohol Repellency Rating ^e (0-10)	Gurley Permeometer (Ft ³ /min/ft ²)	Strength Laminate Bond Test Results (mN)
C-1	Thermally bonded laminate	20 PSI (369 PLI) ^a 270°F Oil Temp.	100.0	0.0 ^b	0.0	3.0	6.0	137.1
C-2	Laminated but not bonded	-----	94.0	4.8 ^b	0.0	4.0	131.0	---
C-MB	Untreated melt blown fabric	-----	76.0	19.7 ^b	0.0	4.0	232.4	---
C-SB	Untreated spunbonded fabric	-----	78.0	22.9 ^b	0.0	3.0	280.0	---

^aNip pressure of 20 pounds per sq. inch (PSI) corresponded to a nip loading force of 369 pounds per linear inch (PLI).

^bThree specimens were tested due to limited sample size; otherwise each value represents five specimens.

^cAATCC test method rates any impact values greater than 5 grams a failure.

^dMaximum oil drop rating in AATCC test method is "8," but the goal in this research was "5".

^eMaximum alcohol drop rating in INDA test method is "10," but the goal in this research was "8."

control samples C-MB and C-SB, the response of sample C-1 was greater than samples C-MB and C-SB. Hence, the oil repellency values are dependent on the fabric selected.

Since both the spunbonded and melt blown fabrics are composed of polypropylene fibers which are hydrophobic by nature, higher water spray ratings were expected. The lower spray rating of the spunbonded and melt blown fabrics alone may be due to differences in surface texture and specimen thickness. Compared with the unfinished spunbonded control fabric alone, the spunbonded fabrics, which were fluorochemically treated by the kiss roll and padding methods (Table X) had improved average spray rating results of 96.0. The FET statistical analysis supported these findings at the 0.05 level. For example, when sample C-SB is compared with a spunbonded fabric treated by the kiss roll method (sample K 40, Table X) and is compared with a spunbonded fabric treated by the padding method (sample P 96), the water spray values were dependent on the fabric selected and its fluorochemical treatment.

The Laminate I Sample Set of the melt blown/spunbonded (MB/SB) laminates were bonded before FC finishing; whereas the Laminate II Sample Set of MB/SB laminates were FC finished before thermal bonding. With the samples finished by the padding, kiss roll, and FFT techniques, the bonding sequence did not alter the water spray test results in that average spray ratings ranged from 98-100 (Tables XI, XII, and XIII).

Table X. Repellency and Barrier Properties of Spunbonded Fabrics Alone Which Were Fluorochemically Finished by the Kiss Roll and Padding Techniques.

Sample No.	Water Spray Rating (0-100)	Water Impact Penetration (grams) ^b	Oil Repellency Rating (0-8) ^c	Alcohol Repellency Rating (0-10) ^d
K 53	98.0	20.3	1.6	8.4
K 40	96.0	21.5	1.6	7.6
K 48-6	90.0	20.3	1.0	7.8
K 40-6	90.0	22.9 ^a	1.6	7.6
P 96	96.0	15.7	2.0	9.0

^aThree specimens were tested due to limited sample size; otherwise each value represents five specimens.

^bSee Footnote "c," Table IX.

^cSee Footnote "d," Table IX.

^dSee Footnote "e," Table IX.

Table XI. Repellency and Barrier Properties of Melt Blown/Spunbonded (MB/SB) Laminates which were FC Finished by the Padding Technique.

Sample No.	Water Spray Test Results (0-100)	Water Impact Test Results (grams) ^b	Oil Repellency Rating (0-8) ^c	Alcohol Repellency Rating (0-10) ^d	Gurley Permeometer _g (Ft ³ /min/ft ²)	Strength Laminate Bond Test Results (mN)
P89	98.0	0.0 ^a	0.0	3.8	11.0	181.3
P2	100.0	0.0 ^a	1.8	6.2	4.4	130.4
P3	100.0 ^a	0.0 ^a	2.0	6.3	5.0 ^a	--

^aSee Footnote "b," Table IX.

^bSee Footnote "c," Table IX.

^cSee Footnote "d," Table IX.

^dSee Footnote "e," Table IX.

Table XII. Repellency and Barrier Properties of Melt Blown/Spunbonded (MB/SB) Laminates which were FC Finished by the Kiss Roll Technique.

Sample No.	Water Spray Rating (0-100)	Water Impact Penetration (grams) ^b	Oil Repellency Rating (0-8) ^c	Alcohol Repellency Rating ^d (0-10)	Gurley Permeometer ² (Ft ³ /min/ft ²)	Strength Laminate Bond Test Results (mN)
K 50	100.0	0.25 ^a	0.33 ^a	5.3 ^a	13.0	160.0
K 20	100.0	0.0 ^a	0.0	4.0	13.5	185.0
K-1	100.0	0.0 ^a	0.0 ^a	4.0 ^a	4.4	271.3
K-2	100.0	0.0 ^a	1.8	4.8	4.0	231.8

^aSee Footnote "b," Table IX.

^bSee Footnote "c," Table IX.

^cSee Footnote "d," Table IX.

^dSee Footnote "e," Table IX.

Table XIII. Repellency and Barrier Properties of Melt Blown/Spunbonded (MB/SB) Laminates which were FC Finished by the FFT Technique.

Sample No.	Strength Water Spray Rating (0-100)	Water Impact Penetration (grams) ^b	Oil Repellency Ratings (0-8) ^c	Alcohol Repellency Ratings (0-10) ^d	Gurley Permeometer Results in ₂ (Ft ³ /min/ft ²)	Laminate Bond Test Results (mN)
F-1	100.0	0.0 ^a	4.4	7.0	8.1	208.5
F-2	100.0	0.0 ^a	4.4	7.0	7.1	204.6
F-3	100.0	0.0 ^a	1.0	4.0	4.5	225.3

^aSee Footnote "b," Table IX.

^bSee Footnote "c," Table IX.

^cSee Footnote "d," Table IX.

^dSee Footnote "e," Table IX.

4.1.2 Effects of Wet Pickup Variations in Different Finishing Methods

Regardless of differences in wet pickup values of the samples which were FC finished by the padding technique, the water spray ratings of the MB/SB laminates and spunbonded samples alone were all excellent, ranging from 98.0 to 100.0. In the padding technique, the concentration of fluorochemical in the bath was adjusted for a wet pickup of 100%. Thus the sample P89 in Table XI was subjected to multiple paddings in an effort to increase the wet pickup towards 100%. The MB/SB laminates finished by both the kiss roll and FFT application methods (Tables XII and XIII) showed no differences in the results of the water spray test regardless of whether either or both sides of the laminate were FC treated. Also, the considerable differences in wet pickup values with the FFT method, (Table XIII) ranging from 7.9 to 60.0%, had no detectable effect on water spray rating. The target wet pickup with both FFT and kiss roll techniques was 50.0%. Furthermore, the spunbonded fabric alone treated by the kiss roll technique (Table X) showed no significant differences in the results of the water spray test regardless of whether these samples were treated on the more deeply or less deeply embossed side. The FET supported these findings at the 0.05 level. When sample K-40, less embossed side, is compared to sample K-53, the more deeply embossed side, it was found that the spray values are independent of the fabric selected. Similar statistical results occurred with the comparisons of samples K 40-6 (less embossed side) and K 48-6 (more deeply embossed side).

4.2 IMPACT PENETRATION TEST RESULTS

The results of the impact penetration tests are discussed in reference to the process considerations: (1) effects of bonding sequence, and (2) effects of variations in different finishing methods.

4.2.1 Effects of Bonding Sequence

The untreated thermally bonded control fabric (sample C-1, Table IX) gave the best possible impact test performance for the control fabrics of 0.0. Even the untreated, unbonded laminated control (sample C-2) sample had a commercially acceptable rating of 4.8 grams. However, according to the Student-Newman-Keuls (SNK) test, sample C-2 was statistically different from sample C-1 at the 0.05 level. Surprisingly, both the untreated melt blown and untreated spunbonded fabrics resulted in high water impact values exceeding 10.0 grams. Apparently, the melt blown and spunbonded fabrics by themselves lacked the strength and/or barrier construction to withstand the force of the penetrating water stream.

All the thermally bonded laminated samples had excellent impact test results as shown in Tables IX, XI, XII, and XIII. The water impact penetration test results were not affected by the thermal bonding temperatures or the thermal bonding sequence. Although the AATCC Test Method 42-1980 recommends that water impact penetration values in excess of 5.0 grams be reported as "greater than 5.0 grams," the total weight of water picked up by the blotting paper was recorded. The spunbonded fabric alone picked up more than 20 grams

of water. Hence, the addition of the melt blown component to form an unbonded MB/SB laminate enhanced impact behavior. This indicates that the melt blown component had a larger effect than either the bonding sequence or fluorochemical treatment method on barrier performance as evaluated by the water impact penetration test.

4.2.2 Effects of Variations in Different Finishing Methods

In summary, regardless of the various percentages of wet pickups arising from squeeze roll pressures from the padder and multiple paddings, the results of the water impact penetration test of the MB/SB laminate samples finished by either padding method were all excellent. The bonded MB/SB laminate samples finished by the kiss roll and FFT techniques showed no notable differences in the impact test results regardless of whether one or both sides of the laminate was treated.

4.3 OIL AND ALCOHOL REPELLENCY TEST RESULTS

All four untreated control samples (the bonded laminate, the unbonded laminate, the melt blown fabric, and the spunbonded fabric alone) showed a poor rating of 0.0 for oil repellency (Table IX). Furthermore, the alcohol repellency ratings for these control samples were only slightly better with ratings ranging from 3.0 to 4.0.

The MB/SB laminate samples which were bonded after finishing (Laminate Set II) regardless of the FC application had oil repellency ratings of 0.0-2.0 while the samples which were thermally bonded before FFT application (Laminate Set I) had oil repellency ratings of

4.4. Otherwise, the oil repellency values for the Laminate Set I samples finished by padding and kiss roll techniques were no better than the Laminate Set II samples.

The FET supported these findings at the 0.05 level. For example, when sample F-1 (an oil repellency value of 4.4), was compared with sample F-3 (and oil repellency value of 1.0), the response (oil repellency values) of sample F-1 was greater than sample F-3. Hence, the oil repellency values are dependent on the fabric selected and its FC treatment. Furthermore, the oil repellency values of 4.4 for F-1 sample and of 0.0 for sample P 89, a Laminate Set I sample treated by the padding method (Table XI), also were dependent on the fabric selected.

The highest oil repellency rating of 4.4 and alcohol ratings of 7.7 in this research were obtained by the FFT finishing technique (Table XIII) on samples which were thermally bonded before finishing (Laminate Set I). However, the wet pickup ranged from only 7.0 to 10.0%. Since the target wet pickup was 50.0%, the actual add on of fluorochemical for samples F-1 and F-2 were only about one-fifth that of Laminate Set II sample F-3 which had oil and alcohol drop ratings of 1.0 and 4.0, respectively. With the FFT technique the fluorochemical finish is concentrated more on the surface of the apparently less permeable Laminate Set I samples, even though the total amount of FC on the fabric is much less than Laminate Set II samples. Likewise, the KET supported these findings because the alcohol values were dependent on the fabrics selected and its FC treatment (samples F-1 and F-3) at the 0.05 level.

4.4 GURLEY PERMEOMETER TEST RESULTS

The Gurley permeometer test indicated that the air permeability of the fabrics are affected appreciably by the bonding sequence and bonding conditions. The air permeability of the unbonded MS/SB laminate was $131.0 \text{ ft}^3/\text{min}/\text{ft}^2$ (sample C-2, Table IX) whereas the air permeability of the unfinished, bonded MB/SB was only $6.0 \text{ ft}^3/\text{min}/\text{ft}^2$. In that Laminate Set I samples (bonded before finishing) ranged from 20 to over 100% greater air permeability values (6.0 - $13.3 \text{ ft}^3/\text{min}/\text{ft}^2$) than did Laminate Set II samples (4.0 - $5.0 \text{ ft}^3/\text{min}/\text{ft}^2$). According to the SNK statistical analysis, Laminate Set I samples K 20, K 50, P 89, and F-1 are statistically different at the 0.05 level from all of the Laminate Set II samples. The lower air permeability of Laminate Set II samples is due likely to the much higher pressures and temperature which were required to bond the laminate components after fluorochemical finishing. Nip pressures between the smooth steel roll and rubber backup roll of 70-80 psig were required, corresponding to a loading force of 1290-1470 pounds per linear inch (PLI), along with a roll heating oil temperature of 325°F . These pressures and temperatures are quite high compared to the 20 psi (369 PLI) nip pressure and 270°F oil temperature required to bond Laminate Set I samples. The appreciably higher pressures and temperatures required to overcome the reduced surface energies of the fluorochemically treated spunbonded and melt blown components to achieve thermal sticking, apparently further reduced the porosity of these laminates.

However, the air permeability of the Laminate Set I samples which range from 6.0-13.3 ft³/min/ft² compare favorably with a 1.9 oz/yd² spunbonded/melt blown/spunbonded (SMS) fabric which was found to have an air permeability of 9.5 ft³/min/ft² (Leonas, 1985). This SMS fabric was thermally point bonded, having approximately 20% total bonded area. Thus, one of the main objectives of the present project may have been attained in that the smooth roll calendering of the melt blown web against the more deeply embossed experimental spunbonded fabric may have achieved a better degree of thermal point bonding.

Generally, as air permeability was reduced, water impact penetration resistance improved. The impact penetration test is considered to be an excellent barrier test (Strickler, 1985). For example, the impact penetration decreased from over 10 grams to 4.9 (samples C-MB and C-2) while the air permeability decreased from 230.0 to 131.0 ft³/min/ft². Further, as the impact penetration decreased from 4.8 to 0.0 grams with samples C-2 and C-1, the corresponding air permeability values were 131.0 and 6.0 ft³/min/ft², respectively. This is also in agreement with the findings of Leonas (1985) who reported that, as air permeability decreased, the penetration of pesticide residues through fluorochemically treated woven and nonwoven fabrics also decreased. In the present study, none of the thermally bonded MB/SB laminates, whether fluorochemical treated or not, had any measureable water impact penetration.

4.5 STRENGTH OF LAMINATE BONDING

The strength of bonded unfinished MB/SB laminate (C-1, Table IX) was rather low at 137.1 milli-Newton (mN) compared to the 1.9 oz/yd² SMS point bonded fabric which had a bond strength of 5688.2 mN. Yet, the bonding strength of these MB/SB laminates may be suitable for disposable protective clothing purposes. Although there was a great deal of variability in the strength of bond test results, Laminate Set I samples had bond strengths from 160 to 209 mN (Table XIII) and Laminate Set II from 130 to 271 mN (Table XII). It is possible that differences in finishing techniques may have served to increase or reduce the bonding effects of thermal calendering, thereby contributing to the wide range in bonding strength. The SNK test at the 0.05 level also confirmed that there was no evidence of a statistical difference in bonding strength.

CHAPTER V

SUMMARY AND CONCLUSION

Agricultural workers are concerned with their increased use of toxic chemicals. They now take more precautions to protect themselves from exposure to these chemicals. In addition to dry chemicals, agricultural workers need protection from water and oil based pesticides.

On the other hand, in the medical profession operating room personnel wear protective clothing and cover the patient with drapes that are designed to provide a more sterile field for the patient. Also, protective clothing is desirable that repels low surface tension fluids that are commonly encountered in operating rooms and other routine activities associated with the medical profession. Although the primary objective is to protect the patient, medical personnel can not wear the apparel for extended lengths of time unless it is comfortable.

Thus, both agricultural workers and medical professionals need a type of protective clothing that provides the required degree of protection and comfort, yet is inexpensive enough for disposable use. The focus of this research is on developing more cost effective methods of applying finishing techniques to relatively inexpensive melt blown/spunbonded (MB/SB) nonwoven laminates to make them suitable for disposable protective garments.

In Chapter One a brief overview of barrier and comfort properties is presented. For a protective garment to be effective, it must be

compatible with certain processes of the human's skin. Terms, such as moisture vapor transmission, wetting, wicking, and permeation of chemical liquids, become important factors to consider when choosing a fabric that is suitable for protective clothing. Polypropylene fabrics offer many characteristics that make it a suitable candidate for protective garments. Generally, polypropylene has high abrasion resistance, good water repellency, excellent wickability, and it is very durable.

Two types of polypropylene nonwoven (melt blown and spunbonded fabrics) are used increasingly in the disposable nonwoven markets. By thermal bonding the melt blown and spunbonded fabrics, a laminate is produced which is especially suitable for disposable nonwoven protective apparel. Methods of thermal bonding are chosen for appropriate web substrates, end-use, and the surface of the material to be treated. Even though the MB/SB laminate was expected to have good barrier properties primarily due to the melt blown component, it was known that fluorochemical (FC) finishing would be required to achieve repellency to low surface energy fluids, such as alcohol and oils. Oils and oil-based materials are encountered in both agricultural and medical-use applications. In applying the FC finish, two low wet pickup techniques, foam finishing and kiss roll application methods, and the high wet pickup technique by padding application, were evaluated. The low wet pickup methods have the advantage of reduced cost since less water needs to be removed during the drying stage. Other researchers also have indicated that improved

performance properties compared to padding can be achieved with these new techniques. Several of them have conducted studies on areas related to nonwoven protective materials. Much of the research focuses on determining barrier properties of the fabrics--Teflon, Tyvek, spunbonded olefins, laminates of paper and polypropylene scrim, and spunbonded and melt blown laminates.

The methodology included three types of material to be tested: (1) a point bonded spunbonded polypropylene fabric alone, (2) a polypropylene melt blown fabric alone, and (3) a melt blown/spunbonded (MS/SB) laminate. Different MB/SB laminate samples were FC finished by the three techniques after thermal bonding in a smooth roll calender (Laminate Set I) and before thermal bonding (Laminate Set II). Three types of finishing techniques were applied to these materials: the Foam Finishing Technology (FFT) process, the kiss roll technique, and the padding method. Finally, specimens underwent six tests: (1) water repellency test, (2) impact penetration test, (3) oil repellency test, (4) alcohol holdout test (5) Gurley permeometer test, and (6) tensile strength of laminate bond test.

The following conclusions were drawn from this study:

(1) Thermal bonding of the melt blown and spunbonded fabric was achieved by using a smooth roll calender. The hypothesis was partially proven in that a degree of point bonded type laminating did appear to result during overall smooth calendering of the point bonded spunbonded and melt blown fabrics. This was evidenced by the air permeability that compared favorably with a commercial SMS point

bonded fabric. However, the laminates also had typical characteristics of smooth roll calendering such as a fairly harsh hand and reduced ability to absorb applied finishes.

(2) The melt blown component of the MB/SB laminate provided excellent water impact resistance irrespective of the order of finish/calendering. On the other hand, the point bonded spunbonded fabrics alone resulted in very poor impact penetration resistance, even after fluorochemical finishing. As was hypothesized, the barrier resistance as measured by impact penetration resistance was mostly due to the melt blown component.

(3) The water spray test results obtained on the MB/SB laminate and the point bonded spunbonded fabric samples which were fluorochemically treated did not differ significantly. Although spray rating of melt blown, spunbonded and MB/SB laminates were greatly improved by fluorochemical finishing, water spray rating performance is largely due to the hydrophobicity of the fibers.

(4) Contrary to the hypothesis that stated that fluorochemical treating of individual components before thermally bonding them (Laminate II Sample Sets) would result in improved repellency compared with laminates which have been thermally bonded prior to repellent finishing (Laminate I Sample Set), the Laminate I Sample Sets had improved repellency by the FFT method. With the FFT technique the fluorochemical finish is concentrated more on the surface of the apparently less permeable Laminate Set I samples, even though the total amount of FC on the Fabric is much less than the Laminate II sample.

(5) The hypothesis was proven in that the Laminate I samples finished by the FFT technique (which is low wet pickup method) had the best oil and alcohol repellency results. Even though area bonding before finishing decreases chemical receptiveness, the FFT process possibly allowed more uniform coverage of more fluorochemical at the fabric surface.

This study investigated a thermal bonding method, bonding sequence and fluorochemical finishing techniques that would provide better repellency, barrier and comfort properties for the laminated fabrics that could be suitable for protective clothing. The limited scope of this study suggests the need for further study in the following areas:

(1) A thermal point bonding process should be used in place of smooth roll bonding to improve comfort, permeability and hand.

(2) A more concentrated fluorochemical finish possibly should be applied to the laminated substrates to enhance oil and alcohol repellency.

(3) A more fundamental understanding of fluorochemical finishing of MB/SB laminate fabrics should be more thoroughly investigated because of the apparent advantages in oil and alcohol repellency gained by the FFT technique versus kiss roll and padding application methods.

(4) Any further study of finishing techniques and thermal bonding nonwoven laminates should include more replications to strengthen confidence in data.

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