CHAPTER I

INTRODUCTION

A major concern for healthcare workers (HCW) is the problem of transmission of pathogens and bacteria from their patients to themselves and the reverse contamination. Dusaj (1993) reported that about one-half of all surgical procedures resulted in an accident where at least one medical worker was contaminated with blood. Any blood contamination could pose a risk of transmission of bacteria (Leonas, 1993). Because of this potential contamination, protection is a major concern. Healthcare workers' uniforms (HCWU), which include surgical gowns, scrub suits, lab coats, and nurses' uniforms, are often used as barriers to help eliminate or reduce the risk of infection for both the doctor and the patient (Granzow, Smith, Nichols, Waterman & Muzik, 1998; Neely & Maley, 2000). Surgical gowns, which were used as early as the 1800s, are traditionally made from cotton fabrics (Smith & Nichols, 1991). Although cotton gowns are comfortable for the wearer, unfinished cotton does not protect against bacterial penetration, or the penetration of biological liquids (e.g., blood, body fluids) and associated bacteria (Beck & Collette, 1952; Laufman, Eudy, Vandernoot, Liu & Harris, 1975; Schwartz & Saunders, 1980). Without sufficient barriers, harmful pathogens can reach and penetrate the skin of surgeons and/or patients, with an associated potential for infection. In addition, when pathogens contaminate HCWU, they can be transmitted to other persons beyond the initial wearer.

For the prevention of surgical infection through contamination from aqueous liquids and bacteria, guidelines have been issued for surgical gowns by several organizations. The Center for Disease Control (CDC) proposed that surgical gowns and drapes, either disposable or reusable, should be impermeable to liquids and viruses and be comfortable to the wearer (Mangram, Horan, Pearson, Silver, & Jarvis, 1999). The Association of Operating Room Nurses (AORN) (1992) suggested that the fabrics used for gown and drapes must minimize passage of bacteria from non-sterile to sterile areas and resist liquid transmission, abrasion, and punctures. In order to have barrier protection, surgical gowns, according to these guidelines, must meet the following criteria: (a) blood and aqueous fluid resistant, (b) abrasion resistant to eliminate bacterial penetration, and (c) lint free to reduce the number of particles in the air. These guidelines emphasized that HCW have a serious concern for barrier protection clothing.

LIFE CYCLES OF TEXTILES FOR HEALTHCARE WORKERS' UNIFORMS (HCWU)

Fabrics that are used for HCWU have two life cycles: reusable and disposable. Reusable fabrics are usually made of a woven fabric and often contain a fiber content of cotton, polyester, or a blend of these two fibers. These fabrics are laundered and sterilized after use in order to remove stains and kill bacteria. Based on Batra's report in 1992, approximately 20% of surgical gowns are of the reusable type. In a cost study, reusable fabrics were found to be more cost-effective than disposable fabrics (DiGiacomo, Odom, Ritota, & Swan, 1992). The benefits of reusable fabric include less solid waste from limited disposal and more comfort to the wearer. In contrast, the problems associated with reusable fabrics include the loss of durability and the reduction of barrier protection after repeated washing (Laufman et al., 1975). If the barrier

protection of the fabric is removed or weakened after repeated washing, the fabric becomes useless as protection for HCW.

On the other hand, disposable gowns are for single use only. They are generally made from a nonwoven fabric and contain either wood pulp/polyester fibers or olefin (i.e., polypropylene) fibers (Huang & Leonas, 1999). Nonwoven fabrics are used extensively in the healthcare industry. In the United States, over three billion yards of nonwoven fabrics, costing $1.5 billion dollars, are used for disposable healthcare products in an average year (Huang & Leonas, 1999). Two benefits of disposable fabrics are that they do not need washing after use (i.e., they are not reused), and they are already sterilized prior to use. By adding a plastic film to disposable fabrics, they can be made impermeable to bacteria. Leonas (1993) studied disposable surgical gowns and found that improved repellency and reduced pore size of these gowns contributed to barrier protection. Some problems associated with disposable fabrics are expense, risk of contamination with disposal outside of the hospital setting, and other environmental issues related to disposal (DiGiacomo et al., 1992). In addition, although a plastic film added to disposable fabrics can increase protection, it could make the fabric bulky, hot, and uncomfortable to the wearer (Hatch, 1993), and increases the problems for disposal solutions.

BARRIER PROTECTION OF TEXTILES FOR HCWU

Both reusable and disposable HCWU have been used to provide barrier protection for HCW (Leonas, 1993; Leonas, 1998; Leonas & Jinkins, 1997). Study results have shown that disposable HCWU could provide better barrier protection if they were reinforced with a plastic film, and reusable HCWU could provide better protection if a textile finish such as a water-repellent finish or antibacterial finish was applied (Huang & Leonas, 1999; Laufman et al.,

1975). A textile finish is defined as "the process of applying mechanical energy, thermal energy, or chemical materials to a textile product to alter its end-use performance" (American Association of Textile Chemist and Colorists (AATCC), 2000, p. 397). One specific textile finish is the barrier protection finish. The barrier protection finish is usually a chemical finish, which is formed by bonding a chemical to the fiber or fabric. Such a finish forms a barrier or coating on the fabric and enhances the fabric's barrier protection properties. Examples of barrier protection finishes are oil/water-repellent and antibacterial finishes. Oil/water-repellent finishes cause oil/water to bead on the fabric surface, while allowing perspiration to pass through the spaces between the fabric's warp and filling yarns (Hatch, 1993). Fabrics with the oil/water-repellent finish can reduce the spread, wetting, and penetration of oil or water on and into the fabric. Laufman et al. (1975) used the water-repellent finish, Quarpel, as a barrier protection finish against the bacteria *Serratia marcesens* and found that the finish inhibits bacterial penetration. Although studies have shown that some water-repellent finish can reduce bacteria transmission, such finishes have had very limited commercial use on HCWU. According to a market survey conducted by the researcher through the Internet in 2002, no oil/water repellent finishes were found on commercially available HCWU; however, a few soil-release finishes were found to be available on some reusable HCWU. Soil-release finishes cannot provide barrier protection. However, by using chemicals such as fluorocarbons to create a more hydrophilic surface, soils and stains could be removed more easily from HCWU with a soil-release finish (Hatch, 1993).

In addition to a water-repellent finish, researchers suggested that antibacterial fabrics could be used to create barrier protection by preventing harmful bacteria from penetrating through the fabric (Collier & Epps, 1999; Hatch, 1993; Smith & Nichols, 1991). Antibacterial agents are chemicals used for a barrier protection finish. These agents are placed on the surface

of the fabric to inhibit bacteria growth and must remain effective after repeated laundering (Brumbelow, 1987). Three types of mechanisms (i.e., controlled-release, regeneration, barrier-block) for antibacterial agents are used to control or inhibit bacteria. The controlled-release mechanism is the most commonly used among the antibacterial agents (Brumbelow, 1987). In the controlled-release finish, chemicals, in the finish, are released from the fabric in enough quantities to kill or inhibit the growth of bacteria. The antibacterial agent, triclosan has been used as a controlled released mechanism on nonwoven fabrics (Huang & Leonas, 1999). The second mechanism is from the regeneration model, which was first established by Gagliardi in 1962. In this model, an antibacterial chemical finish is applied to the fabric and is continually replenished by a bleaching agent during laundering. The antibacterial agent, monomethylol-5,5-dimethylhydantoin (MDMH) has been used as a regeneration mechanism on woven fabrics (Sun & Xu, 1999). The third mechanism is barrier-block, which inhibits bacteria through direct surface contact. The antibacterial agent bonds (i.e., covalent, ionic) to the fabric surface thus making the fabric an effective barrier against bacteria and remains durable during laundering. The antibacterial agent, 3-trimethoxysilypropyldecyldimethyl ammonium chlorine (AEGIS Microbe Shield™ (AMS)) has been used as a barrier-block mechanism on cotton and cotton blended fabrics (Malek & Speier, 1982) as well as polyhexamethylene biguanide (PHMB), which is commercially known as Reputex™, has been used on woven and nonwoven fabrics (Huang & Leonas, 1999; Wallace, 2001). Antibacterial finishes can be found on many products such as hosiery, shoe insoles, towels, underwear, bedding, and active wear (Thiry, 2001); however, no antibacterial finishes were found on commercially available HCWU in an Internet search during Spring/Summer 2002. Personal communication with many suppliers of HCWU (see Appendix A) also failed to identify any HCWU with an antibacterial finish.

STATEMENT OF THE PROBLEM

During every hour of a major surgical operation, about 30,000 to 60,000 organisms are deposited on a three to four meter squared sterile field (Conn et al., 1986). During these operations, one of the primary sources of contamination of HCW is from open wounds. One way of helping to reduce this problem and to protect the workers is to have a proper barrier as part of the HCWU. The HCWU can be disposable or reusable. Disposable gowns are used only once and are good in providing protection; however, the problems associated with disposable fabrics are high-risk contamination, environmental issues through waste and landfill, expense, and discomfort if they are reinforced with a plastic film (DiGiacomo et al., 1992; Hatch, 1993). Reusable HCWU are usually more comfortable than disposable fabrics; however, reusable cotton fabric without a finish does not protect against bacterial penetration (Leonas, 1993).

Penetration of bacteria through the HCWU is a major concern for HCW. For example, bacteria could penetrate through dry fabric in a reusable HCWU by the pressure that a surgeon exerts on the table while operating during surgery (Altman, McElhaney, Moylan, & Fitzpatrick, 1991). If the gown were to become wet with blood, water, or salt solution, bacterial penetration could increase (Beck & Collette, 1952). This penetration of bacteria could contaminate the doctors' skin through the scrub suit that is being worn underneath their gown (Smith & Nichols, 1991). Furthermore, infecting the doctor's skin could potentially increase his/her risk of contracting harmful infections such as HIV, HBV, and hepatitis C (HCV) (Sulzbach-Hoke, 1996).

In addition to surgical gowns, other HCWU such as lab coats and nurses' uniforms are potential sources of contamination primarily as a source of transmission. Lab coats especially at the cuffs are a source for contamination. Infection of the HCWU could be acquired from a doctor

or numerous other hospital sources and transferred to his/her patient (Wong, Nye, & Hollis, 1991). This contamination could occur through bacterial transmission when the same coat is worn in areas such as a patient's room, cafeteria, or bathroom of the hospital/clinic (Littlechild, Macmillan, White, & Steedman, 1992). Nurses' uniforms are also a breeding ground for infection because they come in contact with patients after surgery, when infection normally occurs. A study showed that the bacterium *Staphylococcus aureus* (*S. aureus*) was primarily found on nurses' uniforms after changing the linen of infected patients (Speers, Shooter, Gaya, Patel, & Hewitt, 1969). Both patients and HCW need protection from penetration and transmission.

A procedure to reduce these types of contamination is to add an antibacterial finish to the HCWU to provide better protection for patients and HCW. However, currently no antibacterial finishes were found on fabrics used commercially for HCWU. Examinations of whether an antibacterial finish can effectively reduce bacterial transmission and penetration are needed. Three mechanisms (i.e., controlled-release, regeneration, or barrier-block) of antibacterial agents could be used to control or inhibit bacteria. The first two antibacterial finish methods have known problems in usage with HCWU. Problems with the controlled-release mechanism are its durability after laundering and leaching of the agents from the fabric. Leaching can often cause problems if the antibacterial agents come in contact with skin of HCW. These agents have the potential to affect the normal skin flora, which could lead to extreme skin irritation and cause dermatitis (Sun & Williams, 1999). In addition, leaching can make skin bacteria build a tolerance to the agent. Additional problems for HCWU also occur for fabrics using a regeneration mechanism. The agents that use the regeneration mechanism require chlorine bleaching to

activate its antibacterial properties after laundering; however, over time chlorine can degrade natural fibers such as cotton, which is often used in reusable HCWU (Hatch, 1993).

Barrier-block mechanisms do not pose the problems currently found with the other two methods. The agent that uses the barrier-block mechanism does not leach on the fabric surface and does not need bleaching to continue its effectiveness. They are bonded on the fabric surface and remain fixed to the surface, thereby killing any bacteria that come in contact with the fabric (Malek & Speier, 1982). Chitosan, AMS, and PHMB are three agents that use the barrier-block mechanism and are currently available in the marketplace. Chitosan has been used in many applications such as dietary additives because of its biodegradability and non-toxicity to mammals (Kim, Choi, & Yoon, 1998). However, Lin et al. (2002) indicated that chitosan has water fastness problems after repeated laundering, and therefore, it is not appropriate to be used on HCWU.

AMS, in contrast to chitosan, is found in many antibacterial-containing products such as socks, bed linen, and camping materials (Burlington Industries and Dow Corning Corporation, 1985). Many of these personal use items are often washed. PHMB is found in swimming pool sanitizers, preservation, and personal care products (Payne & Kudner, 1996). In the studies on the efficacy of AMS and PHMB, these two agents have been evaluated as antibacterial agents on the reduction of odor (Malek & Speier, 1982; Payne & Kudner, 1996); however, their efficacy as antibacterial agents on the reduction of bacteria after laundering has been examined only in a limited arena. Malek and Speier (1982), in one study, examined the efficacy of AMS and found that it had significant antibacterial activity when used with a woven fabric. In addition, one study was found on the examination of antibacterial activities of PHMB combined with a fluorochemical compound, a water-repellent agent, on nonwoven gowns before laundering

(Huang & Leonas, 1999). The results showed that PHMB had significant antibacterial activity alone and when it was added to the fluorochemical compound. Payne and Kudner (1996) hypothesized that PHMB would show better durability than AMS due to its ability to bind at the different surfaces of cotton fabric. Their claim was supported by the information that AMS is bound to the fabric through one cationic group, but PHMB is bound to the fabric by multiple cationic groups. However, no study was found with the comparison of the antibacterial activity between AMS and PHMB on fabrics after repeated laundering. Although Payne and Kudner hypothesized that PHMB may have a stronger bond than AMS, AMS may have a lower finish cost than PHMB because a lower amount of AMS than PHMB is required to provide antibacterial activity. According to the agent manuals and personal communications with Dr. Bob Monticello of AEGIS which produces AMS, and Dr. Jana Rajan of Avecia which produces PHMB, 0.5% concentration of AMS is needed in the finish bath compared to 2.3% of PHMB for antibacterial activity.

The purpose of this research is to examine whether antibacterial finishes can effectively reduce the presence of bacteria that have the potential for penetration and transmission on HCWU. The objective of this research is to compare the antibacterial properties (i.e., barrier property against a Gram-positive bacteria and a Gram-negative bacteria), descriptive properties (i.e., fabric weight, fabric thickness), and durability properties (i.e., breaking strength loss due to abrasion) of a 65/35% polyester/cotton blend fabric treated with AMS and PHMB before and after repeated laundering. AMS and PHMB were selected for comparison because these two agents use the barrier-block mechanism to inhibit bacteria. They are non-leaching, which can reduce the risk of skin irritations such as dermatitis, and they do not need bleaching to continue

their effectiveness. These characteristics make the two agents good candidates to be used for the prevention of bacteria on reusable HCWU.

Reusable HCWU need to be laundered often; therefore, the effects of number of laundering cycles on the two agents will be studied. The comparison, after repeated washings, of the antibacterial property of fabrics, initially treated with AMS or PHMB, could determine if AMS has the same or better durability prolonging the effectiveness of the antibacterial finish while using a lesser amount of the agent. Reusable fabrics instead of disposable fabrics are selected because of their wider use and dispersion within the healthcare setting. Disposable fabrics are mainly used in surgical gowns but reusable fabrics are found in various HCWU (e.g., nurses' uniforms, lab coats, and scrub suits). A polyester and cotton blend fabric will be used in this study because it is the most frequently used fabric for reusable HCWU (Needly & Maley, 2000). In addition to the antibacterial property (i.e., barrier property), descriptive fabric properties (i.e., fabric weight, fabric thickness) will also be examined to determine if any changes occurred after treatment and laundering. One durability property (i.e., breaking strength loss due to abrasion) will be examined because a HCW can directly influence the condition of the HCWU through general wear and movement. In fact, if the HCWU were to abrade during the HCW movements, the HCWU, overtime, could allow for increased bacterial penetration.

CHAPTER II

REVIEW OF LITERATURE

This chapter reviews literature important to the problems associated with healthcare workers uniforms (HCWU) and the antibacterial finishes that could be used to increase barrier protection. This review of literature is organized in two sections. The first section on HCWU discusses history, standards, and types of uniforms. The second section on bacteria and antibacterial finishes addresses types of bacteria, spread of bacteria, and compounds that are currently being studied and used as antibacterial finishes.

HEALTHCARE WORKERS UNIFORMS (HCWU)

The Center for Disease Control (CDC) has estimated that 8.8 million people work in the healthcare industry, and 27 million surgical procedures are performed in the U.S. every year (Mangram et al., 1999). From these procedures, surgical wound infections can be transferred from worker to patient or vice versa (Hughes, Culver, & White, 1983). A way to combat these infections occurring from penetration or transmission is for workers to wear proper HCWU. Examples of HCWU are surgical gowns, scrub suits, lab coats, and nurses' uniforms (Neely & Maley, 2000). Matthews, Slater, and Newsom (1985) stated that HCWU should be comfortable, cheap, durable, non-toxic, and able to resist transfer of bacteria.

HISTORY OF HCWU

Pissiotis, Komborozos, Papoutsi, and Skerkas (1997) reported that as early as the 1800s, a need for HCWU especially surgical gowns was recognized because the blood from patients would splatter on the doctor's clothing and skin. Any bacteria in this blood could cause an infection to the doctor. In addition, many patients and some doctors died from bacterial transmission from soiled garments. To help combat this problem, surgeons Lister, Pasteur, and Semmelweis wanted to make an aseptic barrier to help protect both doctors and patients from bacteria in the operating room (Pissiotis, et al.). According to Smith and Nichols (1991), an aseptic barrier is defined as any type of material placed between the operative incision and the possible source of bacteria. Such a barrier is used with the intention of preventing bacterial transmission into the surgical sterile zone. In 1883, Gustav Neuber reported the first use of sterilized surgical gowns and caps in the operating room (Meade, 1968). Sterilized gowns, which were traditionally made of 140-thread cotton muslin fabric, were used as a barrier against bacteria from the late 1800s until 1950s (Smith & Nichols, 1991). Since the 1950s, the use of traditional cotton gowns has decreased significantly due to their lack of protection (Beck & Collette, 1952), and nonwoven, disposable gowns have emerged as a substitute for these reusable cotton gowns. Currently, nonwoven fabrics constitute 80% of materials used in the healthcare industry (Sun, Zhang, Wadsworth, & McLean, 2000).

STANDARDS FOR HCWU

Standards for HCWU are very important for the welfare of healthcare workers (HCW) as well as their patients. Several organizations have made recommendations or mandates on how to

protect HCW as well as patients from exposure to bloodborne pathogens and bacteria. The following organizations have provided detailed information concerning HCWU.

Association of Operating Room Nurses (AORN)

AORN is a professional organization of perioperative registered nurses. This organization promotes quality patient care through education, standards, services, and representation. AORN issued standards as early as 1975 for draping and gowning materials (AORN, 1975). It proposed that surgical drapes and gowns should be made of fabrics that form an effective barrier by eliminating the passage of bacteria between sterile and non-sterile areas. An effective barrier should be fluid resistant (e.g., blood and aqueous), abrasion resistant, and lint free. AORN also recommended that surgical gowns need to be changed after becoming visibly soiled and then laundered in an approved facility, in order to maintain their barrier properties (AORN, 1993). Most importantly, HWCU manufacturers need to provide data to customers (e.g., HCW) regarding the bacteria and liquid barrier performances of their products (AORN, 1992).

Center for Disease Control (CDC)

Since 1946, the CDC is the leading federal agency for the protection of health and safety of U.S. citizens both in the United States and in their travel abroad. Today, the CDC is a vital force in protecting the U.S. public from most widespread diseases that could affect public health. The guidelines of the CDC mandate that surgical gowns should be impermeable to liquids and viruses (Bolyard et al., 1998). If a HCWU (e.g., scrub suit) is soiled, contaminated, or penetrated by any infectious material, the CDC recommends that it be changed immediately.

Occupational Safety and Health Administration (OSHA)

OSHA is a division of the Department of Labor and was established in 1971 to save lives, prevent injury, and protect workers' health. OSHA recommends that appropriate protective clothing must be worn to form an effective barrier when an employee has a potential for exposure on the job (OSHA, 1989). The type of clothing needed depends upon the occupational task and the degree of potential exposure. If the clothes are potentially soiled from blood or other potentially infectious materials, protective clothing must be worn to prevent the employee's underlying clothing from contamination. Fluid-resistant clothing must be worn when workers could become contaminated through splashing or spraying of blood or other potentially infectious materials. Because a larger volume of blood and other potentially infectious materials are associated with the work of the HCW, a specific protective type of barrier clothing is needed. OSHA further recommends that the contaminated uniform should be removed at the end of the work shift. A contaminated uniform should not be taken home but be left at the work area for cleaning, laundering, and/or disposing.

TYPES OF HCWU

HCWU include surgical gowns, scrub suits, lab coats, and nurses' uniforms. They are categorized as reusable or disposable. Scrub suits, lab coats, and nurses' uniforms are often made of reusable fabrics (Neely & Maley, 2000); however, surgical gowns are frequently made of either reusable or disposable fabrics (Granzow et al., 1998). The characteristics of reusable and disposable HCWU are dependent on fiber type, construction, and finishes to determine its optimal usage for protection. Reusable fabrics used for HCWU can be used over 50 times after laundering and sterilization (Sun & Xu, 1998); whereas, disposable fabrics for HCWU are used

only once before being discarded.

Reusable HCWU

Reusable HCWU are used in many aspects of the healthcare industry such as in clinics, hospitals, and veterinary offices. Batra (1992) reported that reusable surgical gowns continue to represent 20% of the total number of HCWU being used. Reusable HCWU are often made of cotton, polyester, or cotton and polyester blend woven fabrics with a plain weave (Neely & Maley, 2000). In a plain weave, the warp yarn operates in an "over-one" and "under-one" pattern with the filling yarn throughout the fabric (Hatch, 1993). This weave pattern can provide a sturdy, comfortable fabric when made from a cotton or a cotton/polyester blend fiber.

Cotton

Cotton is a natural and staple length fiber. The longitudinal view of a cotton fiber looks like a flat, twisted ribbon, and its cross-section is shaped as a flat tube folded together, which resembles a kidney bean (Vigo, 1978). Cotton fiber is made of five regions: cuticle, primary wall, winding, secondary wall, and lumen. The primary wall consists of fibrils, which are very fine structures (Needles, 1981). Underneath the primary wall is the secondary wall that constitutes the bulk of the whole fiber. This wall is made of layers of fibrils, in which the first layer slightly differs from the others. The first layer is called the winding layer. This layer is shown when the fibrils change the direction of their spiral, which causes a weak area in the secondary wall. At this weak area, the fiber can change the direction of its twist. Lastly, the lumen is the hollow canal, which runs the length of the fiber.

The lumen is usually filled with sap; however, once the sap is evaporated, the canal will collapse inward, which forms a kidney bean shape in the cross section. Cotton fabric is used for HCWU because of its properties of comfort, durability, and ease of care (Lee, Cho, & Cho, 1999). The kidney bean shape permits the cotton fiber to contact skin randomly instead of continually, which is considered comfortable especially when the wearer perspires (Hatch, 1993).

The polymer structure of cotton fiber is composed of over 90% cellulose polymers. Cellulose is the most abundant organic substance found in nature (Ege, 1999). Cellulose is a polysaccharide made up of glucose, which contains carbon, hydrogen, and oxygen. The glucose units of cellulose are the most stable in the chair formation and are joined together by a β-1,4'-glycosidic linkages (see Figure 1).

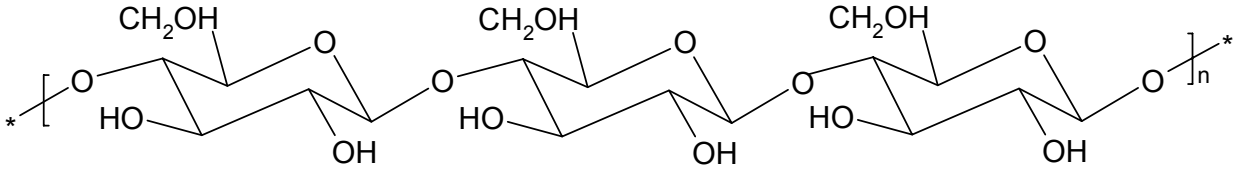

Figure 1. Polymer structure of cellulose

Cotton is a very long structure that resembles a helix. Its degree of polymerization (DP) ranges from 6,000 to 10,000. The DP is the number of repeating units of a polymer. It is often expressed mathematically to estimate the average length of fibers (Gohl & Vilensky, 1983), and is written as follows:

$$\text{Degree of polymerization} = \frac{\text{Average molecular weight of polymer}}{\text{Molecular weight of the repeating unit in the polymer}}$$

Cotton is a durable fiber due to hydrogen bonding of the atoms and has high degree of crystallinity. Cotton has 65-70% crystalline and 30-35% amorphous regions. Crystalline regions of cotton are aligned longitudinally and amorphous regions have voids or holes within the fibers (Gohl & Vilensky, 1983). Most crystalline fibers tend to be stronger, durable, and less absorbent than fibers that are mostly amorphous. Cotton has a good ease of care because it can be sterilized without damaging its structure. The problem associated with cotton use for HCWU is its ineffectiveness in protection of HCW against bacterial penetration and transmission (Pissiotis et al., 1997). Cotton is hydrophilic due to its many hydroxyl (OH) groups (see Figure 1). The OH groups make the fiber polar, which enables the fiber to attract water molecules. This property can increase the wearing comfort of HCWU containing cotton. Absorbency is important to comfort because cotton fibers can wick perspiration from the body of the wearer; however, the water molecules can discharge static electricity on the fiber, which accumulate and act as carriers for bacteria (Vigo, 1978). In addition, the hydrophilic nature of cotton allows for seepage and penetration when cotton HCWU are splashed with liquids (e.g., blood, body fluids).

Polyester

Polyester is a synthetic fiber, which is usually a transparent white or off-white color. The longitudinal view of the polyester fiber reveals a smooth, rod-like shape, and its cross section is round or trilobal (Needles, 1981). The most common type of polyester is polyethylene terephthalate (PET), and it is composed of methylene groups, carbonyl groups, ester links, and benzene rings (see Figure 2).

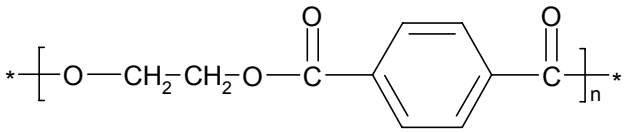

Figure 2. Polymer structure of polyester

HCWU made of polyester are very durable due to the strength of the fibers. Polyester is a strong fiber because of its crystallinity. The linear structure is the percentage of crystallization and alignment along the axis. Its DP ranges from 115 to 140, and its composition is approximately 35% crystalline and 65% amorphous (Gohl & Vilensky, 1983). Although polyester fibers are not as crystalline as cotton fibers, the amorphous region is well-aligned with the fiber axis, and, consequently, resembles a more crystalline structure. The well-aligned amorphous region of the polyester fiber makes the fiber very durable. The round, smooth, and flat shape of polyester can become uncomfortable because the fiber can directly stick to the skin of the wearer.

Polyester is a hydrophobic fiber, which means that it is non-polar and, therefore, does not attract water. The hydrophobicity of polyester can create a fabric environment that becomes uncomfortable if the wearer perspires. The polyester fibers would not be able to wick the perspiration or moisture away from the body, due to lack of hydrogen bonding in comparison to the structure and wicking properties of cotton (Hatch, 1993). In addition, because of the hydrophobic characteristic of polyester, if the garment becomes contaminated, stains will become difficult to remove through laundering (Gohl & Vilensky, 1983).

Polyester and cotton blend

A fabric with a polyester and cotton blend fiber content is the most common fabric type used in HCWU (Neely & Maley, 2000). Neely and Maley reported that polyester and cotton blended fabrics are used primarily for scrub suits, lab coats, and nurses' uniforms. One of the reasons why the blending of polyester and cotton fibers is so successful for HCWU is their combined properties of comfort from cotton fibers and durability from polyester fibers (Hatch, 1993). Fabrics containing a polyester and cotton blend are stronger than fabrics made of 100% cotton and are more absorbent than fabrics made only of 100% polyester.

Comparison of various types of reusable gowns

The fiber content and bacterial transmission have been the focus of some studies using various fabrics found in HCWU. Laufman et al. (1975) conducted a study of bacterial transmission on various surgical gowns' fabrics. One gown was made of a double layer of 100 % regular cotton fabric, and the other gown was made of a single layer of tightly woven 100% Pima cotton fabric. Pima cotton has longer and more uniform staple fibers than regular cotton. No treatment was applied on the double layer regular cotton fabric. The Pima cotton fabric was evaluated in various conditions: (a) before a water-repellent finish, (b) after a water-repellent finish but before washing, and (c) after a water-repellent finish and 2, 25, 55, and 75 laundering cycles and sterilization. The tests for transmission were conducted after 5 and 30 seconds as well as after 1, 5, 15 and 30 minutes. Pressures were exerted on the gowns with weights to simulate stresses that a surgeon exerts during surgical operations. The results from a dichotomous pass/fail table showed that the untreated, double layer, regular cotton fabric and the untreated Pima cotton fabric did not prevent bacterial transmission. The treated Pima cotton fabric did not

show any transmission even after 75 laundering cycles when the test was conducted after 15 minutes of contact. When the test was conducted after 30 minutes of contact, treated Pima cotton fabric that had been laundered for 75 cycles did show bacterial transmission. Comfort changes were not measured in this study.

Leonas (1998) conducted a study that examined the protection properties of several reusable fabrics after laundering. Three woven fabrics, containing one of three fiber contents - (a) cotton, (b) polyester, or (c) polyester and cotton blend were compared. The results showed that only the polyester fabric did not exhibit any penetration of *Staphylococcus aureus* (*S. aureus*) after laundering. It was also reported that Standard Textile Company had a 100% polyester reusable fabric that could retain an effective barrier protection after 75 cycles of laundering and sterilization (Taylor, 1994).

Contrasting results have been found in other studies, which also examined fiber content as a variable in preventing bacterial penetration and transmission. Smith and Nichols (1991) conducted a study on various gown fabrics. One gown was made of a single layer of 50/50% polyester and cotton blend fabric, and the other gown was made of a double layer of 100% polyester fabric. The researchers used an apparatus to simulate abdominal pressure that occurs during surgery. The pressures were evaluated from 0.25 to 2.0 psi between 1 second to 5 minutes. Both gowns allowed maximum 37% and 53% penetration respectively after 5 minutes at pressures exceeding 1.0 psi. Another study was conducted by Leonas and Jinkins (1997) on three reusable surgical gowns. One gown was made of a single layer of 100% polyester fabric, a second gown was made of a double layer of 100% polyester fabric, and the third gown was from a fabric with a single layer of 50/50% polyester and cotton blend. The gowns were tested for liquid penetration and bacterial transmission against *S. aureus* and *Escherichia coli* (*E. coli*). The

results showed that both the single and double layers of the 100% polyester gowns had liquid penetration in three of the six trials. The gown with the double layer of polyester allowed bacterial transmission of *E. coli* and the gown with a single layer of polyester allowed liquid penetration of *S. aureus*. The single layer, 50/50% polyester and cotton blend gown provided no resistance to either liquid penetration or bacterial transmission of *S. aureus* and *E. coli*.

In summary, in one test, untreated Pima cotton fabric did not perform better than untreated regular cotton fabric; however, by adding a water-repellent finish to the Pima cotton fabric, bacterial transmission was inhibited. Mixed results were found in tests comparing fabrics with various fiber contents. Some results showed that a 100% polyester fabric resisted penetration better than a 50/50% polyester and cotton blend fabric (Smith & Nichols, 1991). In contrast some results showed no difference among fabrics with varying fiber contents. Lastly, no difference in barrier protection was found in one study between reusable fabrics with a single layer and reusable fabrics with double layers of the same fiber type (Leonas & Jinkins, 1997).

Disposable HCWU

Disposable HCWU are mainly used for surgical applications. In U.S. operating rooms, nonwoven fabrics are the most commonly used disposable textiles and represent an expenditure of over $1.5 billion per year (Huang & Leonas, 1999). Nonwoven fabrics are used in approximately 80% of all surgical procedures. An average of three billion square yards of nonwoven fabrics is consumed for surgical textiles each year (Sun et al., 2000). Another disposable fabric used for HCWU is tissue, usually fiber or scrim reinforced (Laufman et al., 1975). Scrim reinforced tissue is strengthened by a polyester fiber web, and varies from fiber tissue which is tissue made from fibers (i.e., cotton or polyester).

Nonwoven

Nonwoven fabrics are usually made of extruded continuous filaments arranged in a fiber web. The fibers are bonded together into the web by various techniques (Hatch, 1993). Nonwoven fabrics are manufactured in the following three steps: fiber selection, web formation, and web bonding (Turbak, 1993). The common fiber types selected for disposable surgical gowns are cotton, wood pulp, polyester, and olefin (e.g., polyethylene, polypropylene) (Jinkins, 1994). Web formation is the arrangement of fibers in a web. The web can be formed by several methods. For the dry laid method, the fiber position is the result of the placement of fibers from an air stream or by carding. For the wet laid method, the fiber position is the result of the placement of fibers from a water slurry. For the spun laid method, melted and molten polymers are extruded through spinnerets and laid in the form of a web. Webs may also be formed as a composite of the preceding methods (Hatch, 1993).

Web bonding can be mechanical, thermal, or chemical. The web by itself is very weak; therefore, bonding is needed to provide strength and durability to form the nonwoven fabric (Duckett, Wadsworth, & Sharma, 1995). The bonding of the fibers in the web restricts the movement of fibers and stabilizes the fiber orientation. The void density distribution is also controlled through bonding.

Two of the most commonly used nonwoven fabrics for surgical gowns are made either of woodpulp/polyester fibers or olefin fibers and vary not only in fiber composition but also in bonding methods (Olderman, 1997). The woodpulp/polyester nonwoven fabrics consist of both wood pulp and polyester webs. These fibers are usually mechanically bonded by the hydroentanglement method (i.e., entangling the fibers in the web by water jets with high pressure). Comfort and strength are derived from the alternation of the wood pulp and the

polyester layer. In contrast, the 100% olefin nonwoven fabric is sometimes made of three layers, which are spunbounded, meltblown, spunbounded (SMS), respectively. It has two outer spunbonded webs and a meltblown inner layer that acts as a barrier in between the two outer layers (Timmons, Kobylivke, & Woon, 1994). Spunbonding is a continuous process for forming nonwoven fabrics starting from the extrusion of the man-made filament fibers to the bonding of the fibers. Meltblown is another bonding process similar to spunbonding; however, after the extrusion of the man-made filament fibers, the fiber web is formed by breaking the fibers into pieces before the fibers are bonded.

Comparison of various types of disposable gowns

Laufman et al. (1975) tested various disposable surgical gown fabrics for bacterial penetration of *Serratia marcesens*. These fabrics came from different manufacturers and were made of a (a) single layer of spun-laced nonwoven, (b) single layer of wet-laid nonwoven, (c) scrim reinforced tissue, (d) fiber reinforced tissue, and (e) spread tow plastic film composite. A pressure of two kilograms (kg) was used to simulate a surgeon's elbow as he/she leans on the operating table. After five minutes of contact, the fiber reinforced tissue allowed bacterial transmission in most of the trials, and the wet-laid nonwoven failed in one of six trials. After 15 minutes of contact, both the scrim reinforced tissue and the spun-laced nonwoven allowed some bacterial transmission. After 30 minutes of contact, all of the tested surgical gown fabrics allowed bacterial transmission except one fabric. Only the spread tow plastic film composite fabric remained impermeable to bacterial transmission.

Smith and Nichols (1991) also studied various types of disposable gown fabrics. One was made of wood pulp/polyester spun-lace, and the other was an olefin SMS. The evaluated gowns

were (a) a single layer of fabric, (b) a reinforced fabric with a layer of the same fabric, or (c) a fabric reinforced with an impervious material. The fabrics were tested with a pressure apparatus. The single layer, wood pulp/polyester spun-laced gown fabric had a maximum of 92% liquid penetration. The double layer fabric of wood pulp/polyester spun-laced had a maximum penetration of 73%. The single and double layers of olefin SMS gown fabrics allowed 30% and 9% penetration respectively. All of the gown fabrics that were reinforced with impervious fabrics had no (0%) penetration.

Leonas (1993) studied bacterial transmission on five disposable fabrics that were commercially available. Three of the fabrics were made of wood pulp/polyester, and two were made of olefin. Among the three wood pulp/polyester fabrics, two were a single layer composition but were manufactured by separate companies. The third wood pulp/polyester fabric was a double layer composition. The two olefin fabrics were either a single or double layer. The bacteria used in the test were *S. aureus* and *E. coli*. The results showed that all fabrics allowed no bacterial transmission, except one of the single layer wood pulp/polyester fabrics. The author indicated that this fabric allowed bacterial transmission because the pore size of this fabric was significantly larger than pore size of the other fabrics. Leonas and Jinkins (1997) conducted a similar study on disposable gowns from several manufacturers and found similar results to Leonas' study. The gowns in the Leonas and Jinkins study were made of either wood pulp/polyester or olefins that were either single or double layers. The single and double layered fabrics of the wood/pulp polyester content gowns did not result in any liquid penetration; however, both the single and double layers of olefin content gowns had liquid penetration in one and two of the six trials, respectively. Although the olefin content gowns did allow some liquid penetration, none of the gowns allowed bacterial transmission of *S. aureus* and *E. coli*.

In summary, the length of contact of fluids on the gowns made a difference in the amount of transmission (i.e., the longer the contact, the greater rate of bacterial transmission). Variations in fiber content and fabric construction provided varying degrees of protection against bacterial transmission. Olefin SMS nonwoven was better than wood pulp/polyester spun-laced nonwoven in protection against liquid penetration; however, regular olefin nonwoven fabrics had similar results in bacterial transmission to the wood pulp/polyester nonwoven fabric. In addition, contradictory results were found regarding the function of layers in bacterial protection. In one study, nonwoven gowns with double layers of woven fabrics were superior to those with a single layer; however, two other studies showed that no differences in bacterial transmission were found between nonwoven gowns with a single layer and double layers of the same nonwoven fabric. One constant result was that nonwoven gowns with plastic or some other impervious fabric did not allow any liquid penetration or bacterial transmission.

Comparison of reusable and disposable gowns

Protection

Garibaldi, Maglio, Lerer, Becker, and Lyons' (1986) study showed that there was no difference in barrier protection from reusable gowns made of polyester/cotton blend woven fabrics and disposable gowns made of polyester spun-laced nonwoven fabrics, used with intraoperative and postoperative wound infections. From the data of 500 patients' operations, this study revealed that the bacterium *S. aureus* was found on 13.1% of reusable and 15.5% of disposable gown fabrics. The authors concluded that the bacteria protection of reusable and disposable fabrics were similar. Laufman et al. (1975) studied various types of reusable and disposable gowns and found that after 30 minutes of contact, reusable Pima cotton fabrics treated

with a water-repellent finish did not allow bacterial penetration even after 55 laundering cycles. The disposable fabrics made of a spread tow plastic film composite also did not allow any bacterial transmission. In contrast, both untreated reusable gowns and non-reinforced disposable gowns allowed bacterial penetration after 15 minutes of contact. The study of Smith and Nichols (1991) showed that both single and double layers of wood pulp/polyester spun-lace disposable fabrics allowed a liquid penetration of 92% and 73% respectively. The single layer of 50/50% polyester and cotton blend reusable gown fabric allowed a maximum penetration of 37%, while the double layer of 100% polyester gown fabric allowed a maximum penetration of 53%. The single and double layers of olefin SMS disposable fabric allowed only 30% and 9% penetration respectively. All disposable gowns with an impervious fabric layer prevented penetration in all trials. Leonas and Jinkins (1997) also found that reusable fabrics allowed some liquid penetration and bacterial transmission, but disposable fabrics with an impervious layer prevented liquid penetration.

In summary, results varied in the comparison of reusable and disposable gowns for barrier protection. One study showed that disposable gowns had better protection than reusable gowns (Smith & Nichols, 1991), and the other study showed no difference (Leonas & Jinkins, 1997). To prevent bacterial penetration, a finish such as water-repellent finish possibly needs to be added to reusable fabrics, and an impervious layer needs to be added to disposable fabrics.

Comfort

Clothing comfort is a state of an individual's satisfaction indicating physiological, psychological, and physical harmony between the person and their environment (Branson & Sweeney, 1991; Slater 1986). The length of time worn, type of operation for which the uniform

is used, and the fiber content and construction of the garment are important factors in determining comfort for the wearer. The comfort of HCWU is important for several reasons. When doctors feel hot in their uniforms, their performance may be impaired in the operating room or in the office (Smith, 1986). In addition, when a protective garment is not comfortable, it is not worn. If not worn, the HCWU is not providing a protective barrier to the HCW.

In order to achieve comfort, a balance of heat produce by the body and the change in environmental conditions are needed (McCullough, 1993). Moisture transmission, heat transmission resistance, and air permeability are the three factors that can mimic this balance (Byrne, Carty, & Scriven, 2000). For a garment to be considered comfortable, water vapor transmission from the skin must occur. When fabrics come in contact with the skin, the fabric should be able to transport perspiration so that a wearer is no longer feeling wet (Cheng & Cheung, 1994). Cotton reusable HCWU are usually more comfortable than HCWU made from other fiber contents because of its better water vapor transmission, which enables water to wick from a workers' skin. This transmission is due to the polar hydroxyl groups on cotton, which are able to attract water to the fabric (Hatch, 1993). Air permeability of a textile fabric is the "degree to which the material is penetrable by air" (Collier & Epps, 1999, p.297). The air permeability of a reusable gown is affected by yarn and fabric structure (Mehta & Narrasimham, 1987). The tighter the twist of the yarn and the closeness of the fabric, the less air will permeate through the fabric. The air permeability of a nonwoven disposable gown is affected by the distribution of the fibers and the pore size in the fabric (Leonas, 1993). Disposable gowns reinforced with a plastic film are usually hotter than reusable gowns because no air can permeate through the plastic reinforcement. Studies have reported that if a worker is uncomfortable in their uniform, they are more likely not to wear it properly (Hoagland & Maurice, 2000; Smith, 1986).

Cost

The costs of reusable and disposable HCWU are difficult to ascertain because the cost of a gown represents not only the manufacturing and retail cost but also the values of safety and comfort (Pissiotis et al., 1997). In general, disposable gowns are considered to cost more because of the large storage space needed for fresh gowns and the continued disposal fees for used gowns (Hatch, 1993). Smith and Nichols (1991) reported that disposable gowns were $3 - $7 each only with one use and reusable gowns were initially about $60, which resulted in an average of $1 per usage. DiGiacomo et al. (1992) reported a study comparing the expenses of operation rooms in two hospitals. One hospital used disposable gowns and the other used reusable gowns. The hospital that used disposable gowns spent $155,664 per year compared to an expenditure of $35,680 in the hospital that used reusable gowns. The figure for the expense of disposable gowns included the disposal cost, and the figure for the reusable gowns included the long-term expense of reusable gowns such as cost of washing, sterilizing, and repackaging. Comparisons are not exact because data from surgical gown companies are not standardized. The Baxter Healthcare Corporation stated that disposable and reusable gowns cost $3.10 and $3.60 per use respectively (Jinkins, 1994). Another surgical gown company, Medline, calculated that reusable gowns cost about $3 per use and disposable gowns were $4 per use (Anders, 1993). According to the market survey through the Internet by the researcher of the current study, in 2002, reusable gowns ranged between $15 and $25 per gown depending on brand and style with an expected lifetime of at least 25 times, and most disposable gowns cost between $40 and $100 for 30-50 pieces per case with an average per gown price of $2. Using the 2002 data in comparison to the data in previous studies, the prices of both reusable and disposable gowns have been reduced over the past 10 years.

BACTERIA AND ANTIBACTERIAL FINISHES

In the healthcare industry, workers risk being infected by bacteria that could be transferred by skin, blood, dust, and perspiration. Researchers and healthcare workers have debated which type of antibacterial finish could be used to hinder the spread of bacteria. This section reviews literature related to bacteria and antibacterial finishes. The section on bacteria discusses type and spread of bacteria. The section on antibacterial finishes addresses the common process used to apply the antibacterial finish and the compounds currently used as antibacterial finishes.

BACTERIA

Bacteria, a type of microbes, are tiny creatures that individually are too small to be seen with the naked eye; however, they can have a major impart on the human life. In order for bacteria to survive, they need to thrive in an everyday environment by metabolizing nutrients such as food or water. Food can be in the form of skin cells and dust, while water is extracted from humid air, body perspiration, other body fluids, or a wet textile (Gruender, 1996). Bacteria are single cell or unicellular creatures that appear in three forms: spherical (cocci), rod (bacilli), and spiral (spirillum), and they can be arranged in pairs, clusters, or chains. Bacteria contain a cytoplasmic membrane and a rigid layer (McCall, Stock, & Achey, 2001). The cytoplasmic membrane is the internal structure that consists of a nucleoid and ribosome. The nucleoid is the DNA of the cell and the ribosome translates genetic messages to proteins. The rigid layer, also called the surface layer, consists of the capsule, cell wall, and plasma membrane. The capsule protects the cell wall and maintains the overall shape of the cell. The plasma membrane is used to transport ions, nutrients, and waste. Some forms of bacteria have appendages that consist of

pilus and flagellum. Pilus allows bacteria to attach to other cells, and flagellum provides the motility for the cell.

Type of Bacteria

Bacteria can be identified as either Gram-positive or Gram-negative, which can be distinguished by the content and structure of their cell wall through a staining procedure called Gram-stain (McCall et al., 2001). If the bacteria remain purple after the procedure, they are Gram-positive; whereas, if no stain appears, they are Gram-negative.

Gram-positive bacteria

Gram-positive bacterium contains peptidoglycan and teichoic acids. Peptidoglycan comprises 90% of the cell wall and is made of amino acids and sugar (McCall et al., 2001). Teichoic acids are responsible for the antigenic determinant of the organism. One example of Gram-positive bacteria is *S. aureus* that appears in pairs, short chains, or grape-like clusters (Jinkins, 1994). It ranges in size from 0.5 μm to 1.0 μm. The temperature for growth ranges from 35-40 °C. *S. aureus* is the major cause of cross-infection in hospitals and makes up 19% of total surgical infections (Huang & Leonas, 2000). *S. aureus* also can cause boils, skin infections, pneumonia, and meningitis especially in a debilitated person (Prescott, Harley, & Klein, 2002). It is also responsible for scaled skin and toxic shock syndromes.

Gram-negative bacteria

Gram-negative bacteria are similar to Gram-positive bacteria except they have an additional layer of outer membranes attached to their peptidoglycan layer by lipoproteins

(McCall et al., 2001). The outer layer is made of lipopolysaccharide and porin. Porin is used to transport low molecular weight substances. One example of Gram-negative bacteria is *Klebsiella pneumoniae* (*K. pneumoniae*). Its shape is like a bacillus, and it appears as single, pair, or short chains (Singleton, 1995). *K. pneumoniae* is the major cause of urinary tract infection, septicemia, and pneumonia in people with compromised immune systems. The bacteria can be transmitted via the fecal-oral route, mouth and throat, air to the lungs, and more importantly through the hands of hospital personnel. The symptoms of *K. pneumoniae* include fever, difficulty breathing, chest pain, and bloody stool (Singleton, 1995). Another example of Gram-negative bacteria is *Escherichia coli* (*E. coli*). *E. coli* is shaped like a bacillus and lives in the intestines of humans. It can spread through the handling and eating of raw food. The symptoms of *E. coli* are severe diarrhea especially in children and kidney damage (Sussman, 1997). Gram-negative bacteria are harder to reduce than Gram-positive bacteria because of the extra cell wall on Gram-negative bacteria (Kaplan, 2000; Murray, Niles, & Heeren, 1988). The study results of Murray et al. confirmed that Gram-negative bacteria (i.e., *E. coli* and *Pseudomonas aeruginosa* (*P. aeruginosa*) were harder to reduce than Gram-positive bacterium (i.e., *S. aureus*).

Spread of Bacteria

Bacterium cannot move from location to location by itself; instead, it must be transported by a carrier such as blood, perspiration, alcohol, shed skin, or dust (Leonas, 1993). The carrier can be transported by either liquid or air. Liquid transport provides a wet or moist transfer of bacteria. The air transport is a dry transport that occurs in the air, usually through vents.

Liquid transport

Liquid transport of bacteria can occur through blood, saline solution, perspiration, and/or water, which are commonly found in a hospital/clinic setting. If the proper barrier is not used, various infections such as *S. aureus* and *E.coli* can be transmitted from patient to healthcare worker (Leonas & Jinkins, 1997). The actual liquid transport can occur through external forces acting against HCWU (Flaherty & Wick, 1993). The external force could result, by a pressing or leaning motion of the HCW, against an object such as an operating or examining room table.

Air transport

Air transport of bacteria can occur through the air movement of dust, particles, and shed skin. It has been reported that humans can shed an average of 1,000 bacteria per minute, which can be a major source of contamination in an operating room (Whyte, Vesley, & Hodgson, 1976). Bacteria from dead skin cells of medical workers can contaminate patients during surgery. Bacteria in the air that can settle on surgical instruments can indirectly contaminate a patient's wound. The amount of bacteria falling from the air is dependent on the length of surgery, number of air changes through the air vents, turbulence in the air, number of times doors open, heat convection from surgical lamps, and a number of people present in the room during a surgery situation (Ritter & Marmion, 1987). The most common type of bacteria that is shed in surgery is *S. aureus* (Mitchell & Gamble, 1974). Skin cells that can affect patients range in size from 5 to 60 micrometers (Mackintosh, Lindwell, Towers, & Marples, 1978). The small size can enable the bacteria to fall or pass between the pores of cotton muslin surgical fabrics (Schwartz & Saunders, 1980).

ANTIBACTERIAL FINISHES

Antibacterial agents were used on textiles thousands of years ago, when ancient Egyptians used spices and herbs as preservatives in mummy wraps (Seong, Kim, & Ko, 1999). Antibacterial finishes continue to be very important in some situations especially for cotton fabrics because the fabrics have poor resistance to microorganisms (Seventekin & Ucari, 1993). An antibacterial finish is a method used to reduce the spread of microorganisms by either killing or inhibiting their growth through contact with the fabric surface (Huang & Leonas, 1999). A durable antibacterial finish must be able to (a) control bacteria or fungi on the cloth, (b) remain effective over the lifetime of the treated article, (c) durable to washing and bleaching, (d) have no risk of adverse dermal or systematic affect, (e) provide no detrimental effects on fabric properties such as yellowing, hand, and tensile strength, (f) coexist with other finishes, such as softeners and resins, and (g) have a low environmental impact (i.e., free of heavy metals, formaldehyde, phenolic, organic halogens) (Payne & Kudner, 1996; Seong et al., 1999).

Several processes are used to apply antibacterial finishes to fabrics. The pad-dry-cure process is the primary process used to apply antibacterial agents to textiles (Yang, Corcoran, Vorlicek, & Li, 2000). For the pad-dry-cure process, water and chemicals are applied to the fabric in a bath, and the fabric is then passed through rollers under pressure so that the chemicals can be pressed into the fabrics. After rubbing, the fabric is dried in an oven and finally cured in the oven at a higher temperature to ensure bonding.

Compounds used in antibacterial finishes

Current antibacterial agents that are used in either industry or academia have three mechanisms: controlled-release, regeneration, and barrier-block.

Controlled-release mechanism

The controlled-release mechanism is the most commonly used of the antibacterial agents. The agent is released gradually in enough quantities to kill or inhibit the growth of bacteria. Examples of antibacterial agents that use controlled-release mechanism are gentamincin and triclosan.

Gentamincin. Gentamincin is an aminoglycoside antibiotic complex. Each component consists of five nitrogen's per mole of gentamincin base (Sigma-Aldrich, n.d.) (see Figure 3). Gentamincin is widely used in hospitals as an antibiotic and acts by inhibiting bacteria protein synthesis (Cho & Cho, 1997). Cho and Cho conducted a study on a dual functional finish using the antibiotic gentamincin as an antibacterial agent and a fluorochemical as a blood repellency agent on surgical gown fabric. The findings showed a 98% reduction of Gram-positive *S. aureus* and Gram-negative *K. pneumoniae* on both 100% cotton and 55/45% woodpulp/polyester spun-laced nonwoven fabrics.

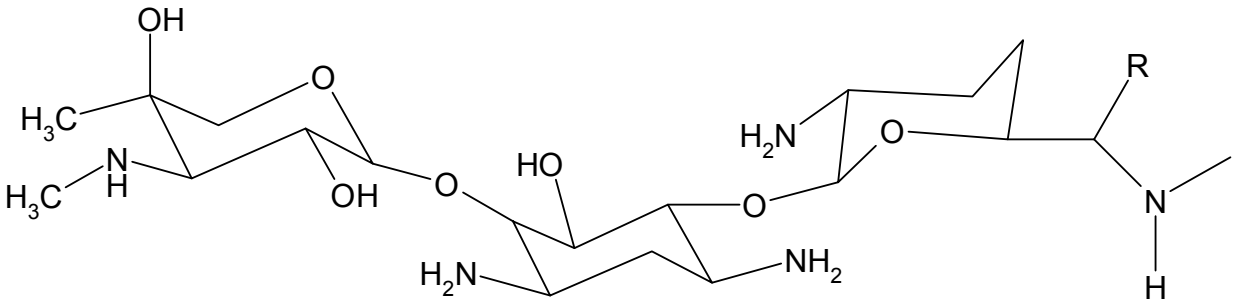

Figure 3. Structure of gentamincin

Triclosan. Triclosan is a diphenyl ether derivative known as 5-Chloro-2-(2,4-dichlorophenoxy) phenol (Huang & Leonas, 1999) (see Figure 4). It is a broad-spectrum

antibacterial/antimicrobial agent that has been incorporated into personal care products such as toothpaste, soaps, deodorants, antiperspirants, body washes, detergents, cosmetics, antimicrobial creams, lotions and hand soaps (Huang & Leonas, 1999). Triclosan interrupts the cytoplasmic membrane of the bacteria that in turn interferes with the metabolic function of the cell. Once triclosan is inside the bacterium cell, it can poison a specific enzyme that the bacterium needs to survive. It has bacteriostatic activity against a wide range of both Gram-positive and Gram-negative bacteria. Some of the negative features of triclosan are that it may cause cancer in humans and creates skin irritations (Bajaj & Sengupta, 1992). Huang and Leonas (1999) examined triclosan as an antibacterial finish along with a fluorochemical repellent finish on nonwoven fabrics. They found that a 0.25% add-on of triclosan was sufficiently high to inhibit bacterial growth of *S. aureus*.

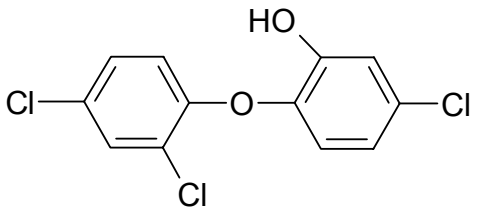

Figure 4. Structure of triclosan

Regeneration mechanism

Gagliardi first developed the regeneration mechanism in 1962. With the regeneration mechanism, an antibacterial chemical finish is applied to the fabric and is continually replenished by bleaching agents during laundering. An example of this mechanism is MDMH.

Monomethylol-5,5-dimethylhydantoin (MDMH). MDMH is a hydantoin derivative (Sun & Xu, 1999) (Figure 5). In the past, MDMH was used as a renewable disinfectant for

swimming pools (Sun & Xu, 1999). It was also known to provide durable and regenerable antibacterial activity for fabrics that contain cellulose. The MDMH, which would kill the cell membrane, is covalently bonded with the fabric and laundered with chlorine bleach to replenish the antibacterial activity of the fabric (Sun, Xu, Bickett, & Williams, 2001). Sun and Xu (1999) researched MDMH, which was used as a finish against *S. aureus* and *E. coli* bacteria on 100% cotton and 65/35% polyester/cotton blended fabrics. When MDMH was used as a regenerated antibacterial finishing agent, it showed significant inhibition on both the Gram-positive and Gram-negative bacteria as well as maintaining the tensile strength of both fabrics after 20 repeated washings.

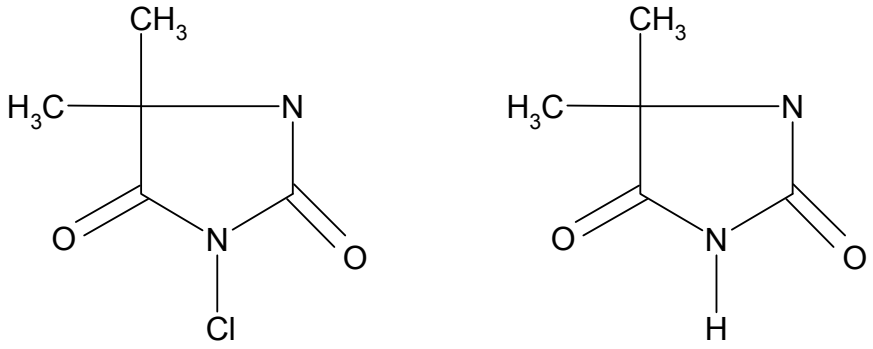

Figure 5. Structure of MDMH

Barrier-block mechanism

Barrier-block mechanism inhibits bacteria through direct surface contact. The antibacterial agent can bond covalently to the fabric to form a strong and durable bond (Brumbelow, 1987). Agents with the barrier-block mechanism do not leach and have fewer problems in skin irritation than agents with the controlled-release mechanism (McCall et al., 2001; Vigo, 1994). In addition, they require less add-on (i.e., less antibacterial agents) on fabric

(Brumbelow, 1987). Examples of agents with the barrier-block mechanism are polyhexamethylene biguanide (PHMB), chitosan and AEGIS Microbe Shield (AMS).

Polyhexamethylene biguanide (PHMB). PHMB is the basic compound of Reputex 20. PHMB is an oligomer with an average of 12 biguanide per molecule (Huang & Leonas, 2000) (see Figure 6). It has been used in swimming pools, cosmetics, and the food industry for many years because of its activity against Gram-positive and Gram-negative bacteria, fungi, and yeast (Payne & Kudner, 1996). PHMB antibacterial activity is through the biguanide functional group, which disrupts the bacterial cell membrane (Huang & Leonas, 2000). Payne and Kudner (1996) studied the effect of PHMB on odor reduction for cotton toweling. They compared the bacterial count of *S. aureus* for the untreated fabric, the softener treated fabric, the 0.2% PHMB treated fabric, and the softener and 0.2% of PHMB treated fabric. The results show that fabrics treated with both PHMB and softener had the lowest bacterial count and followed by the 0.2% of PHMB treated fabrics (i.e., $4x10^4$, $6x10^5$ respectively). The bacterial count of the softener treated fabric was also lower than that of untreated fabrics (i.e., $2.6x10^9$, $>10^{10}$ respectively) but the difference was not as significant as the difference between the PHMB treated fabric and the untreated fabric. The authors concluded that the amount of *S. aureus* and odor were reduced when 0.2% PHMB was used. When Gram-negative bacteria (i.e., *Proteus vulgaris (P. vulgaris)*, *E. coli*, *P. aeruginosa*) were tested on cellulose pulp, the authors measured amounts of bacteria and amounts of ammonia in order to have a more quantitative assessment of odor control. The authors found that as the concentration of PHMB increased (i.e., 125ppm, 250ppm, 500ppm, 1000ppm), the amounts of ammonia detected were reduced after 8 and 24 hours respectively. However, they could not correlate bacterial population with amount of ammonia reduced. Huang

and Leonas examined PHMB as an antibacterial agent against *S. aureus* on two nonwoven fabrics: SMS and woodpulp/polyester spun-laced. The results showed that a 0.75% add-on of PHMB along with a flourochemical finish were sufficient to inhibit *S. aureus* in both types of fabrics.

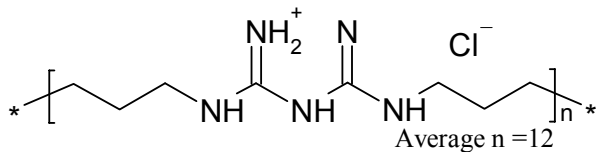

Figure 6. Structure of PHMB

Chitosan. Chitosan is a derivative of chitin, which is the second most abundant natural polymer. Its structure is very similar to that of cellulose except one of the hydroxyl groups is replaced by an amino group (Ege, 1999) (see Figure 7). Chitosan can destroy bacteria by converting its amino group into an ammonium salt in dilute acid solutions. QAS can destroy the cell wall of the microorganism by connecting to its negatively charged protoplasm (Kim et al., 1998). Chung, Lee, and Kim (1998) used chitosan as an antibacterial finish along with a durable press finishing agent on 100% cotton fabrics and found that antibacterial activity remained to a level of 80% after 10 repeated launders. Lee et al. (1999) evaluated chitosan as an antibacterial agent along with a blood repellent finish. The researchers found that the treated cotton fabric showed higher reduction (97%) in the number of colonies of *S. aureus* bacteria compared to the number of colonies on a 55/45% woodpulp/polyester spun-laced nonwoven fabric. One of the problems with chitosan is wash fastness (Shin, Yoo, & Jang, 2001). The finish does not last through repeated washing and is not regenerated.

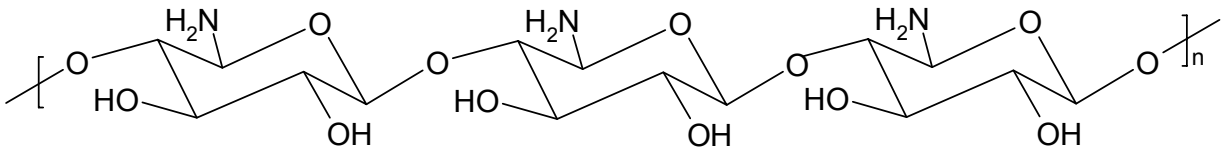

Figure 7. Structure of chitosan

AEGIS Microbe Shield (AMS). AMS is known as 3-trimethoxysilylpropyldimethyloctadecyl ammonium chloride, which is a combination of QAS and alkoxysilane (Malek & Speier, 1982) (Figure 8). The QAS of this compound is able to rupture the cell membrane of bacteria, and the silanol is used to covalently bond the finish to the surface of the fabric. The chemistry process of attaching AMS on a fabric surface occurs in two steps. The first step is the ion exchange process where AMS replaces the protons from water on the surface of the fabric. The water forms a negative electrical charge at the water and surface interface. The second step is the polymerization of the silicon group being coated on the surface. Products that are treated with AMS include cotton/polyester sheeting, carpeting and throw rugs, outerwear fabrics, underwear, nylon hosiery, nonwoven fabrics, mattress ticking, and filter fabrics (Burlington Industries and Dow Corning Corporation, 1985).

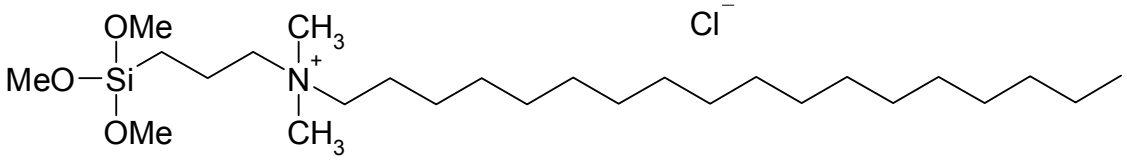

Figure 8. Structure of AMS

Burlington Industries and Dow Corning Company (1985) did an in-house study on the effect of AMS on the odors caused by bacteria in 75/25% ORLON®/nylon knitted socks and found that AMS can significantly reduce the odor of socks, even after laundering. ORLON® is a

trademark for acrylic fiber. The findings showed that AMS was bonded to the socks and was not removed after 40 repeated laundering. The presence of AMS on socks provided three functions. AMS had a hydrophobic character, which inhibited intimate contact of microorganisms on the socks. It also masked the unpleasant odor and imparted antibacterial activity. Murray et al. (1988) examined the antibacterial effect of AMS against various Gram-positive bacteria (i.e., *S. aureus, Staphylococcus epidermidis*) and Gram-negative bacteria (i.e., *E. coli, K. pneumoniae*) on a treated polyester/cotton fabric versus an untreated polyester/cotton fabric. The AMS concentration levels ranged from .05% to 1% (i.e., .05%, .10%, .30%, .50%, .75%, 1.0%). The findings showed that AMS at all concentration levels except .05% were effective in inhibiting all Gram-positive bacteria by more than 95% reduction; however, the Gram-negative bacteria were not inhibited by any concentrations of AMS. However, Malek and Speier (1982) reported that AMS reduced both *S. aureus* and *E. coli* on cotton fabric by analyzing photomicrographs of the fabric surface before and after laundering; although the specific number of times laundered was not revealed. White and Gettings (1985) also studied bacteria reduction against Gram-positive (i.e., *S. aureus*, *Streptococcus faecalis*) and Gram-negative (i.e. *E. coli* and *P. aeruginosa*) bacteria. In their study, AMS was not applied directly on the fabric; therefore, the antibacterial activity of the solution was measured. The result showed that the Gram-positive bacteria were inhibited in a 10μg/ml solution and the Gram-negative bacteria were inhibited in a 100μg/ml solution. Ten times of the amount of AMS solution was needed to be able to inhibit the Gram-negative bacteria.

CHAPTER III

METHODS

This chapter discusses the hypotheses, research design, materials used to conduct this study, test procedures, test methods, and data analysis. The first section lists the hypotheses that were generated from the objective featured in Chapter 1. In the second section, research design addresses the assumptions and limitations of the study. The third section is materials, which discuss the fabric and antibacterial compounds used in this study. The fourth section is test procedures, which include the processes of finishing, laundering, and specimen cutting. The fifth section explains the test methods for antibacterial, descriptive, and strength testing. The last section, data analysis, discusses the analysis of the results.

HYPOTHESES

The purpose of this research is to examine whether antibacterial finishes can effectively reduce the presence of bacteria that have the potential for penetration of and transmission on HCWU. The objective of this research is to compare the antibacterial properties (i.e., barrier property against a Gram-positive bacteria and a Gram-negative bacteria), descriptive properties (i.e., fabric weight, fabric thickness), and durability properties (i.e., breaking strength loss due to abrasion) of a 65/35% polyester/cotton blend fabric treated with AEGIS Microbe Shield (AMS)

and polyhexamethylene biguanide (PHMB) before and after repeated laundering. Based on the objective of the research, eight hypotheses were examined:

1. There is no significant difference in antibacterial activities among three treatments (i.e., AMS, PHMB, no treatment) against *S. aureus* or *K. pneumoniae*.
2. There is no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on antibacterial activities against *S. aureus* or *K. pneumoniae*.
3. There is no significant difference in fabric weight among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment).
4. There is no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on fabric weight.
5. There is no significant difference in fabric thickness among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment).
6. There is no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on fabric thickness.
7. There is no significant difference in breaking strength loss due to abrasion among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment) in the warp direction or filling direction.
8. There is no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on breaking strength loss due to abrasion in the warp direction or filling direction.

RESEARCH DESIGN

Based on the objective of the research, an experimental design with a 3 X 4 factorial design was developed for each test property (i.e., antibacterial activity, fabric weight, fabric thickness, breaking strength loss due to abrasion). The experiment included three variations of treatment - two finishes (i.e., AMS, PHMB) and a control with no added finish, and four selected laundering cycles (i.e., 0, 5, 10, 25). AMS and PHMB were selected for comparison because they are commonly used and commercially available antibacterial agents. Both agents are non-leaching and do not need bleaching to regenerate their effectiveness against bacteria; however, PHMB has a larger number of cationic groups than AMS, which could be a basis for better antibacterial activity. By increasing the binding to cotton fabric through the cationic groups, PHMB could be more durable than AMS especially after laundering. Although PHMB may have a stronger bond than AMS, AMS may have a lower finishing cost than PHMB because of the lower amount of AMS required to provide antibacterial activity. According to both agents' manuals and personal communications with Dr. Bob Monticello from AEGIS Environments that produces AMS and Dr. Jana Rajan from Avecia Microbiocides that produces PHMB, a 0.5% concentration of AMS is needed in the finish bath compared to 2.3% of PHMB for antibacterial activity.

With this nonparallel information about the viability of these two agents, a comparison study was needed to determine if AMS had the same or better antibacterial properties than PHMB while using a lesser concentration. In addition, a control group (i.e., no treatment) was included as a standard for comparison with the agent treatments. The four laundering cycles (i.e., 0, 5, 10, 25) were selected based on the study by Wallace (2001), who examined the antibacterial activity of PHMB on cotton fabric after 0, 1, 5, 10, and 25 laundering cycles. Some significant

changes in PHMB antibacterial activity were found with laundering; however, the results from the Wallace study showed no significant differences in the reduction of *Staphylococcus aureus* (*S. aureus*) between the first and the fifth cycle. For this reason, the evaluation of the antibacterial activity after one laundering cycle was omitted in this study. The polyester/cotton blend woven fabric was selected for this study because it is a commonly used fabric for HCWU (Needly & Maley, 2000). Both Gram-positive (i.e., *S. aureus*) and Gram-negative (i.e., *K. pneumoniae)* bacteria were selected in this study because they represent major sources of bacterial infection in hospitals (Jinkins, 1994).

With these variables, the research design resulted in 12 experimental cells for each test (see Table 1). For antibacterial testing, three trials were conducted for each cell. According to information from Avecia Microbiocides, the laboratory that performed the antibacterial test portion of this study, the three-test trial is the standard in the industry (J. Rajan, personal communication, 2003). The Avecia Microbiocides Laboratory director, Dr. Jana Rajan, explained that the quality control standards of the lab and the accuracy of testing procedures ensure that three trials are sufficient for reliability of data. In addition, the three-trial test was used in a similar study on antibacterial properties of nonwoven gowns, in a paper that received an AATCC Graduate Student Award (Jinkins & Leonas, 1994). In addition to the testing of antibacterial properties, the descriptive properties (i.e., fabric weight, fabric thickness) and durability property (i.e., breaking strength loss due to abrasion) of AMS and PHMB treated fabrics before and after laundering were evaluated. A similar 3 x 4 research design for the examination of the four physical properties were used, resulting in 12 tests per property. Five trials were conducted for each test (see Table 1).

Table 1. Research Design for Antibacterial, Descriptive, and Strength Test Properties

Test Properties		**Finishing Treatments**	**Number of Trials**			
			Laundering Cycles			
			0	**5**	**10**	**25**
Antibacterial Property	**Bacteria reduction**	AMS	3	3	3	3
		PHMB	3	3	3	3
		No treatment	3	3	3	3
Descriptive Properties	**Fabric weight**	AMS	5	5	5	5
		PHMB	5	5	5	5
		No treatment	5	5	5	5
	Fabric thickness	AMS	5	5	5	5
		PHMB	5	5	5	5
		No treatment	5	5	5	5
Durability Properties	**Breaking strength loss due to abrasion**	AMS	5	5	5	5
		PHMB	5	5	5	5
		No treatment	5	5	5	5

Note: Number of trials varies with test requirements

ASSUMPTIONS AND LIMITATIONS

Two assumptions were made for conducting the procedures in this experiment. First, equipment and operator error were assumed to be of a random nature and had no significant effect on the results from the tests. Second, all of the chemicals purchased and donated were used as received because all reagent grades were assumed consistent with the labeling information.

The study had three major limitations. First, although the antibacterial activity of AMS and PHMB may differ on assorted fabrics, only 65/35% polyester/cotton blend fabric was examined in this study. Second, although the antibacterial activities after higher laundering cycles may yield different results from lower numbers of cycles, antibacterial testing was only conducted after the three selected laundering cycles (i.e., 5, 10, 25). Third, although the potential for numbers of antibacterial agents was limited only to the development of said agents, only two

antibacterial agents were selected (i.e., AMS, PHMB). The limitations affected the generalizability of the findings, especially with regard to other fabrics and other agents.

MATERIALS

Fabric

Fourteen yards of 65/35% Dacron® polyester/cotton blend fabric were purchased from Testfabrics, Inc. The reason for selecting this fabric was that it had been used in a recent study on the regeneration of antibacterial properties of halamine (Sun & Xu, 1999) and was commonly used in HCWU, as seen available in catalogs and on websites. The fabric was a 45" bleached fabric with the code number #7409. Based on the catalog information from Testfabrics, Inc., the fabric weight was 104 g/m^2, the fabric thickness was .0250", and the fabric count was 78 x 86. Before conducting any finishing or other testing, tests of fabric weight, fabric thickness, and fabric count were conducted to confirm the information of fabric from Testfabrics, Inc.

Antibacterial Compounds

Two compounds were used in this study: AMS and PHMB. Both AMS and PHMB were discussed in Chapter 2 and their structures are shown in Figure 8 and Figure 6 respectively. AMS and PHMB are commercially available antibacterial agents from AEGIS Environments in Midland, MI and Avecia Microbiocides, Wilmington, DE, respectively, and both agents were generously donated from the companies for this research.

TESTING PROCEDURES

Finishing Process

The most widely used method for the antibacterial finish is the pad-dry-cure process (Yang, Corcoran, Vorlicek, & Li, 2000). In this study, however, padding and drying were the only parts of the process used for adding antibacterial finishes on the 65/35% Dacron polyester/cotton blend fabric. Curing was omitted because the antibacterial agents can attach to the fabric through covalent bonding when water is added; therefore, curing was not necessary (Malek & Speier, 1981; J. Rajan, personal communication, 2003).

A stock solution of each agent was prepared. According to the instructions from each antibacterial agent's manual, 0.5% and 2.3% concentration solutions were prepared for AMS and PHMB respectively (i.e., 5.0 grams of AMS was added to 1000 ml of water and 23.0 grams of PHMB was added to 1000 ml of water). The solution was hand-stirred with a glass rod to ensure even distribution. The solution for the control experimental group (i.e., no treatment) contained only 1000 ml of water, and was not stirred. For finishing, the test fabric was placed on a two-roll padder and then immersed in the bath followed by padding through squeezed rollers to a wet pick-up of 95-100% based on weight of fabric (owf). After padding, the fabric was dried at 120°C for five minutes in an oven. A single layer of appropriately sized test fabric was processed through the padder and dried until all the needed fabrics were finished.

After finishing, two verification methods (i.e., scanning electron microscopy (SEM), acid dye test) were used to ensure that AMS and PHMB were successfully applied to the fabric. In SEM, electromagnets are used to bend an electron beam, which is used to produce the image on the screen (Reimer, 1998). An International Standards Instrument ISX-430 SEM, from the Department of Chemistry at Virginia Polytechnic Institute and State University, was used to

compare the surfaces of the finished and unfinished specimens. The researcher was trained on this instrument and able to determine a successfully finished specimen by analyzing at the surface, which should look smoother and more uniform compared to the unfinished specimen. For the acid dye test, a small swatch of each treated and no treatment fabrics were immersed in a canister filled with a blue acid dye solution to verify qualitatively if AMS and PHMB were on the fabrics. Both AMS and PHMB have a nitrogen group; therefore, the dye adhered to the nitrogen group and formed a blue stain on the fabric, verifying the treated fabric's existence.

Cutting Plan for Pre- and Post- Finishing

Fourteen yards (yd) of 65/35% Dacron® polyester/cotton fabric, 45" wide, were purchased for the study. Within any standard fabric, the selvages of the fabric are usually constructed differently from its body and are often heavier to protect the fabric from damage due to handling (Merkel, 1991); therefore, to ensure the validity of the fabric in fabric sampling, no specimen was taken nearer than one-tenth of the width along the fabric selvage edge. To accommodate this exclusion, the 45" wide test fabric was cut 4.5" from the selvage edge. The resulting 36" width fabric was cut lengthwise into two 18" wide strips (14 yards long) because the maximum width that can be fitted in the two-roll padder is 18". Prior to padding, the 18" fabric strips were cut to yield 15 sections of 56" x 18". Five sections were used for each treatment (see Figure 9). After cutting the sections and before adding the antibacterial treatment, the test fabric was spread on a table in a conditioning room for 24 hours according to ASTM D 1776-96 Standard Practice for Conditioning Textiles for Testing. The conditions for this method were specified at a relative humidity of 65 ± 2% and temperature of 21 ± 1 °C (70 ± 2 °F).

After finishing and verification, and before laundering, each 56” x 18” section was cut into four swatches of 14” x 18” for use in each laundering cycle (see Figure 9). This cutting resulted in 20 swatches, sized 14” x 18” for each treatment, or 60 swatches overall. Each swatch was marked, using a permanent pen with the treatment and laundering cycle information. The coding system for laundering was shown in Appendix B. The numbering system identified type of treatment (i.e., AMS (A), PHMB (P), no treatment (N)), laundering cycle (i.e., 0, 5, 10, 25), and section number (i.e., 1 to 5). For example, an AMS treated fabric at 0 laundering cycle in the first section was recorded as A.0.1 (see Appendix B). In addition, with the exception of the swatches for testing at the 0 laundering cycle, the edges of the rest of the 14” x 18” swatches were sewn on a serger machine to help prevent the fabric from unraveling during washings.

The laundry plan, also shown in Figure 9, detailed the assortment of the laundering cycles throughout the test fabric. The cycles differed across the sections with a rotation of order across the swatches. The purpose of changing the order of laundering cycles was to include different fillings yarns for swatches used in each laundering cycle so that the swatches provide a better representation of the test fabric at each laundry cycle.

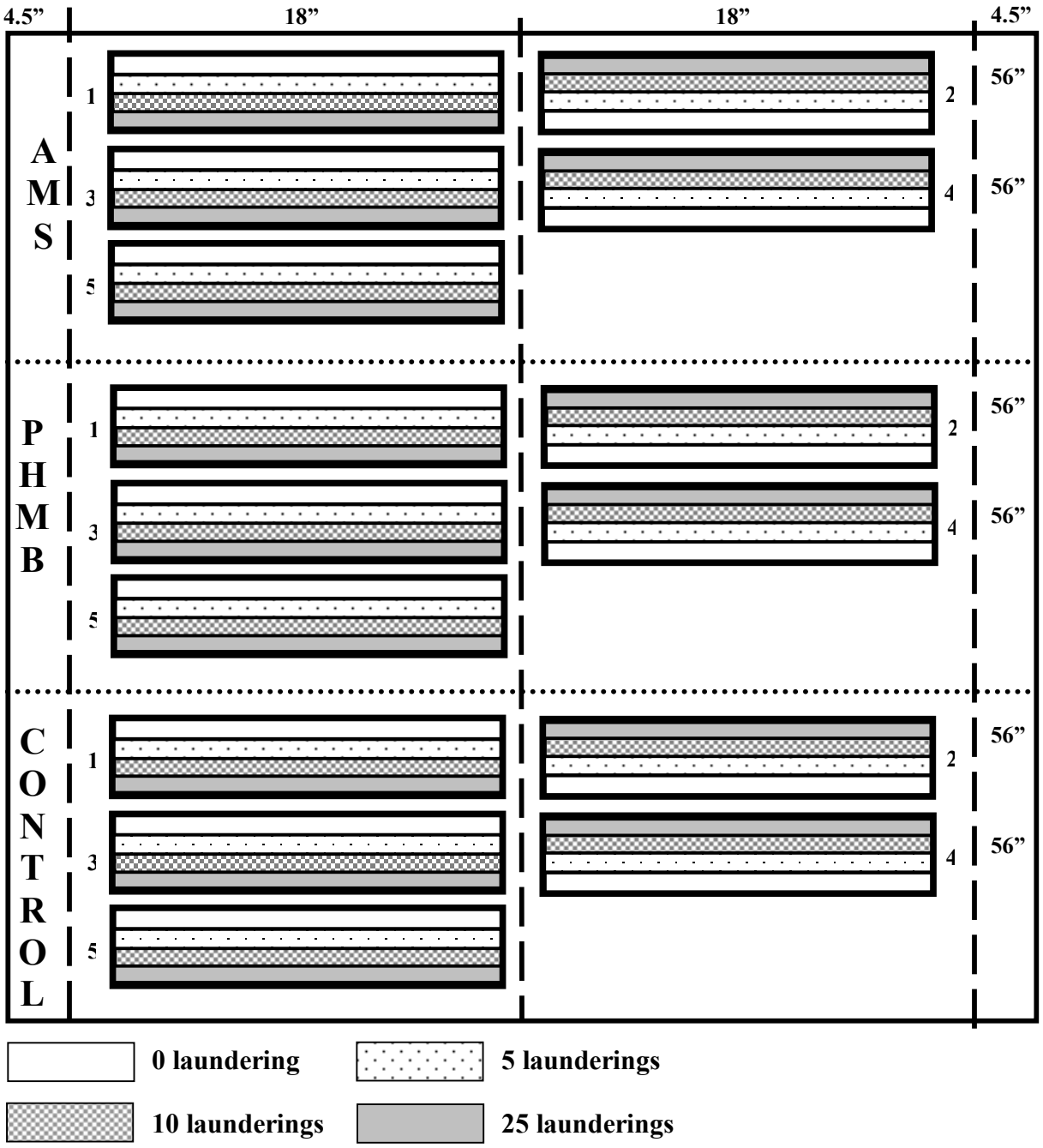

Figure 9. Cutting plan of test fabric (two 18” strips) to yield 15 sections for finishing and 60 swatches for laundering

Note: The proportion of each section and swatch is not to actual size.

Laundering

All swatches were washed based on AATCC Test Method 143-96: Appearance and Other Textile End Products after Repeated Home Laundering. A MAYTAG Model A806 (MAYTAG Company, Newton, IA) washer and dryer were used. Three swatches from the same 56" x 18" section were washed together to represent one test trial, and consequently, the laundering process was repeated five times for each treatment. The laundering procedure steps were as followed:

1) According to the AATCC Test Method 143-96 for the washing machine condition of polyester/cotton blend, the washing machine was set on regular wash, regular spin, hot wash, warm rinse, and normal water level conditions in which the water temperature was set to 49 ± 3 °C (120 ± 5°F).
2) According to the Wallace (2001) study of PHMB, 66.0 ± 0.1 g of TIDE Quick Dissolving Detergent was added to the washing machine.
3) Ballast, a plain woven fabric**,** was added to the machine for washing with the swatches to make a 4.00 ± 0.13 pound (lb) load.
4) The swatches were washed approximately 12 minutes with an additional six minutes for the final spin cycle.
5) According to the AATCC Test Method 143-96 for the dryer conditions of polyester/cotton blend, the washed load (swatches and ballast) was placed in MAYTAG Model DE806 dryer on the regular setting in which the exhaust temperature was set at 66 ± 5°C (150 ± 10 °F) with a cool down time of 10 minutes.

After five laundering cycles, the swatch marked for five laundering cycles was removed and put in a coded plastic bag. The remaining two swatches were laundered continuously for an

additional five cycles to equal 10 laundering cycles. After 10 laundering cycles, the sub-swatch marked for 10 laundering cycles was removed and put in a coded plastic bag. The final swatch was laundered continuously for an additional 15 cycles to equal 25 laundering cycles. After 25 laundering cycles, the final swatch marked for 25 laundering cycles was put in a coded plastic bag. For each treatment, the same procedure of laundering and removing swatches was repeated.

Specimen Cutting for Testing

After the laundering process was completed, from most of the 14" x 18" swatches, three specimens were cut, one for antibacterial testing, one for fabric weight and fabric thickness, and one for breaking strength loss due to abrasion. Different cutting plans were needed to prepare test specimens that best represent the whole fabric. The specimen cutting plans are illustrated in Figures 10, 11 and 12. The cutting plan A shown in Figure 10 is made from the first (or top) two sections (i.e., sections 1 and 2 in Figure 9) of the fabric used for each treatment. In these two sections, the 14" x 18" swatches have the same cutting plan; however, as noted earlier, the laundering cycles differ from the left section to the right section. The cutting plan B shown in Figure 11 represents the third and fourth sections for a treatment and has a similar laundry arrangement to cutting plan A (see Figure 10); however, the position of specimens to be cut differs from that of cutting plan A. In addition, only three antibacterial specimens were needed for treatment, and these were obtained from the cuttings of the swatches in cutting plans A and C (see Figures 10 and 12); therefore, no swatch for the antibacterial test was cut from the swatches in cutting plan B (see Figure 11). Cutting plan C (see Figure 12), represents the fifth section within a treatment, and has the same cutting arrangement as cutting plan A. Cutting plans A, B and C were repeated for each treatment portion of the fabric. All of the specimens were cut 1"

from the edge of each 14” x 18” swatch due to structure distortion that could occur during the finishing and laundering processes.

As previously noted, specific cutting criteria for the antibacterial properties testing results only in three specimens in 4” x 4” squares cut from each laundering cycle within each treatment. Immediately after cutting, the specimens for the antibacterial test were (a) placed separately according to the treatment and the laundering cycle in sealed plastic bags, (b) checked for coding with the numbering system as shown in Appendix B, and (c) sent to Avecia Microbiocides in New Castle, DE for antibacterial testing.

For descriptive properties (i.e., fabric weight, fabric thickness), five specimens were cut in 4” x 4” squares for testing fabric weight and thickness. Because the area of the specimen needed to be very precise to determine the fabric weight, a 4” x 4” die was used to cut these specimens. For the durability property (i.e., breaking strength loss due to abrasion), 10 specimens were cut. Five specimens in the size of 4” (warp) x 12” (filling) were used for testing the warp direction and the other five specimens in the size of 12” (filling) x 4” (warp) were used for testing the filling direction. Immediately after cutting, the specimens for the descriptive and durability tests were placed separately according to the treatment and the laundering cycle in sealed plastic bags, and labeled.

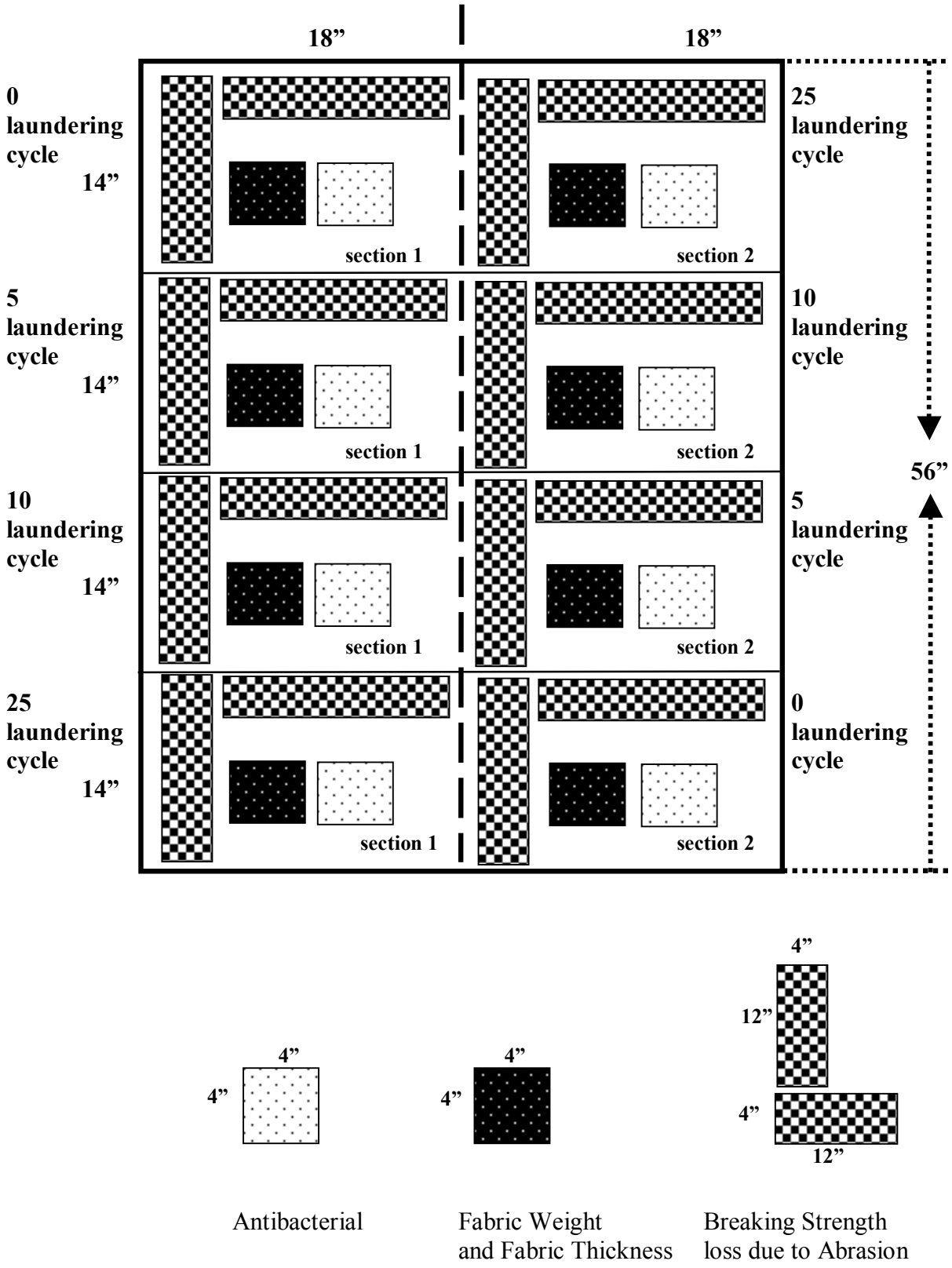

Figure 10. Specimen cutting plan A, within sections 1 and 2 of a treatment

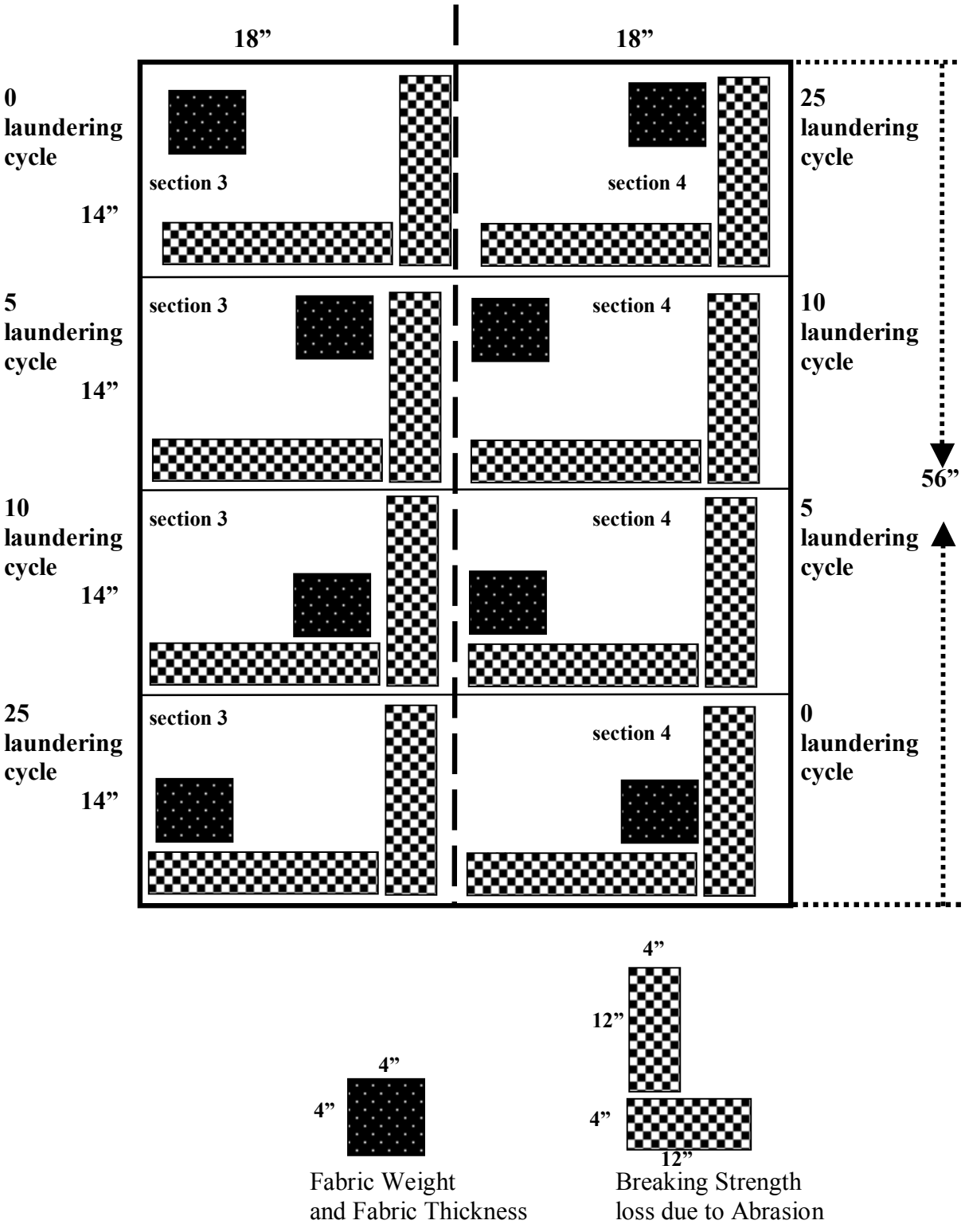

Figure 11. Specimen cutting plan B, within sections 3 and 4 of a treatment

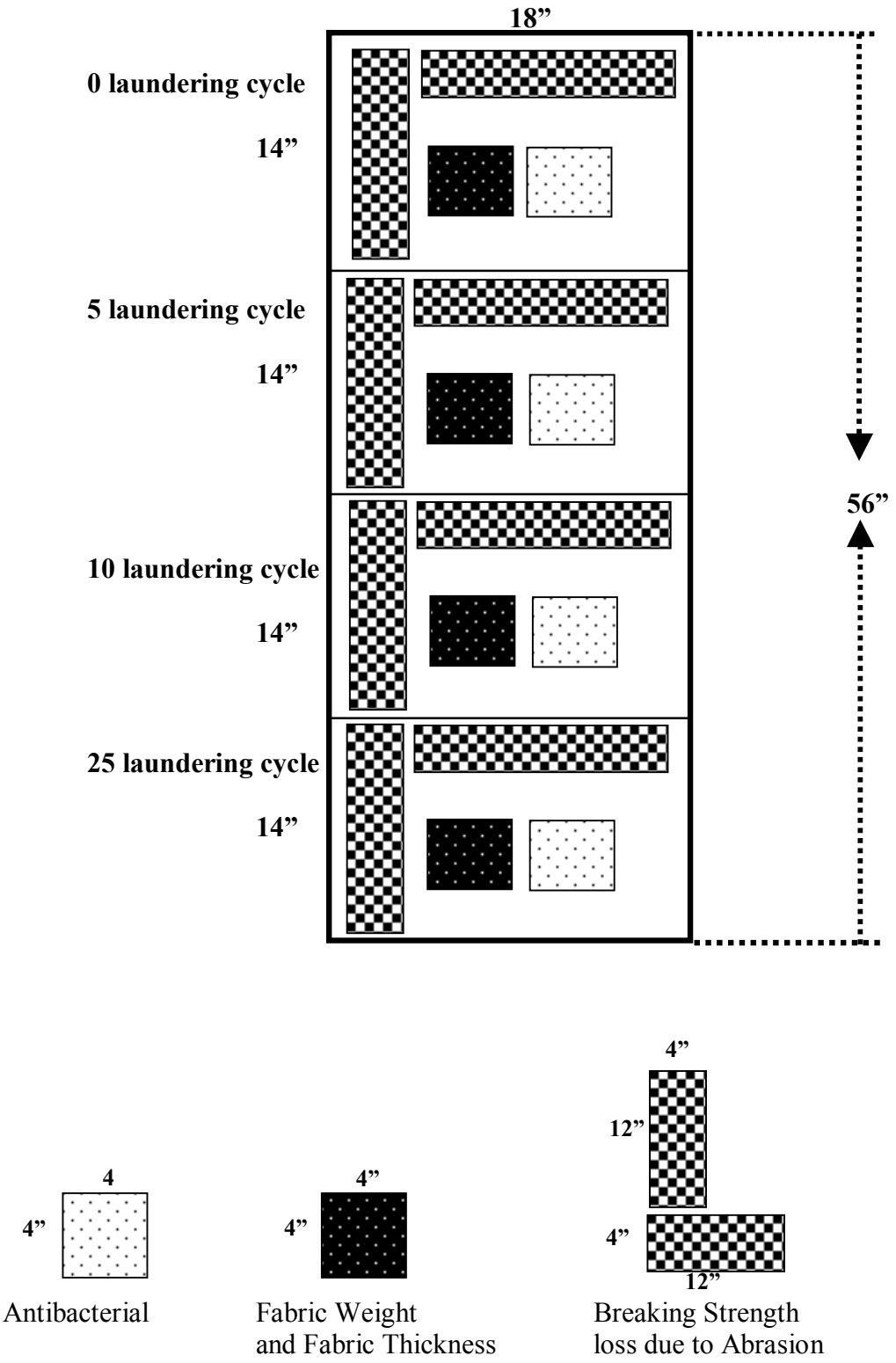

Figure 12. Specimen cutting plan C, within section 5 of a treatment

TEST METHODS

Antibacterial Testing

Antibacterial properties of the treated test fabric against Gram-positive bacterium (i.e., *S. aureus*) and Gram-negative (i.e., *K. pneumoniae*) were determined by the test method of AATCC 100-1999, Antibacterial Finishes on Textile Materials: Assessment of (AATCC, 2000). The testing was conducted at the Avecia Microbiocides laboratory under the direction of Dr. Jana Rajan. A total of 36 swatches in 4" x 4" squares, three for each experimental cell, was provided for the tests of antibacterial activity (3 treatments x 4 laundering cycles x 3 trials = 36). To test the antibacterial activities against two bacteria (i.e., *S. aureus*, *K. pneumoniae*), the specialist at the Avecia Microbiocides laboratory cut each 4" x 4" swatch in half. The procedures of the antibacterial test are described in the following steps:

1) Each bacterium was shaken for 24 hours and stood for 15 minutes before the inoculum was prepared.
2) Each swatch was placed flat separately in sterile petri dishes and a microliter pipette was used to inoculate them ensuring an equal distribution of the inoculum.
3) Each swatch was transferred to a sterile, 250 ml screw cap, Erlenmeyer flask. Immediately after inoculation ("0" contact time), 100 mL of neutralizing solution was added to each flask.
4) The flask was capped and shaken vigorously for 1 minute ± 5 seconds.
5) To determine the bacterial concentration of the solution in each flask at "0" contact time, serial dilutions of bacteria was taken. After serial dilutions, the amount of bacterial was counted on a plate.

6) All solutions were incubated for 48 hours at 37 °C ±2°C followed by a count of the colonies that formed on the dish.
7) The values were recorded and averaged by the following formula:

Log Reduction (CFU/ml) = log (A/B)

CFU = colony forming units

A = number of bacteria recovered from treated fabric after 24 hours

B = number of bacteria recovered from treated fabric at zero contact time

Descriptive Testing

Fabric Weight

Fabric weight was measured according to the ASTM D 3776-96 Standard Test Method for Mass Per Unit Area (Weight) of Woven Fabric, Option C- Small Swatch of Fabric. A Denver Mettler balance was used to measure the fabric weight of five 4" x 4" specimens to the nearest 0.001g for each experimental cell (see Table 1). The weight was reported in grams per meter squared (g/m^2).

Fabric Thickness

Fabric thickness was measured according to the ASTM D 1777-96 Standard Test Method for Thickness of Textile Materials. The same specimen used to test the fabric weight was also used to test fabric thickness. A pressure of 3.59 Newton (N)/meters $(m)^2$ was placed on the fabric specimen for five seconds before the measurement is taken. Fabric thickness was measured to the nearest 0.001".

Durability Testing

Breaking Strength loss due to Abrasion

The test of abrasion resistance was conducted according to AATCC Test Method 93-99 Abrasion Resistance for Fabrics: Accelerotor Method. The Accelerotor method was selected because this method simulates all three types of abrasions: flat, flex, and edge abrasions, which may occur at various locations in HCWU. Because fabric strength is important for HCWU, the strength loss method was used to evaluate the abrasion resistance by comparing the breaking strength of the original and abraded specimens. To ensure the same warp yarns were used in the original and abraded specimens, the specimens were first cut in 4" (warp) x 12" (filling) and then cut in half into two pieces of 4" (warp) x 6" (filling) specimens. To ensure the same filling yarns were being tested, a specimen of 12"(warp) x 4" (filling) was cut in two pieces. One specimen was kept as the original and the other was abraded using an Accelerotor Test Instrument. The specimen was placed in the Accelerotor at 2000 ± 100 rpm for 2 minutes**.** After abrasion, the breaking strength was evaluated on both original and abraded specimens. The breaking strength loss due to abrasion was determined according to the ASTM D 5034: Test for Breaking Force and Elongation of Textile Fabrics (Grab Test). In the grab test, the specimen was cut wider then the clamps and gripped in the middle. This test gives a more accurate measurement of the strength loss after abrasion of the total fabric, instead of the strength loss after abrasion of the yarns gripped between the clamps. The Instron Constant Rate of Extension (CRE) was used to measure the breaking strength. The specimen was placed between the upper and lower clamps and pulled apart slowly and consistently. The force required to pull apart the specimen was reported as the breaking strength. The percentage (%) strength loss due to abrasion was calculated according to the following formula:

$$\% \text{ strength loss} = \frac{\text{original strength} - \text{abraded strength}}{\text{original strength}}$$

DATA ANALYSIS

The software, Statistical Package for the Social Sciences (SPSS), was used to analyze the data. The data analysis included two types of statistical analysis. The first analysis used descriptive statistics (i.e., mean) of each test property: bacteria reduction, fabric weight, fabric thickness, and breaking strength loss due to abrasion. Table 2 and 3 were used to report the percentage reduction of antibacterial activities against *S. aureus* and *K. pneumoniae* respectively. The second analysis employed inference statistics (i.e., comparison of means). Multiple Analysis of Variance (MANOVA) was used to test Hypotheses 1 and 2 to examine the influences of the antibacterial treatments, laundering cycles, and the interaction between the treatments and laundering cycles on the reduction of *S. aureus* and *K. pneumoniae*. Two-Way Analysis of Variance (ANOVA) was used to examine Hypotheses 3 to 6 to determine the effects of the antibacterial treatments, laundering cycles, and their interaction on fabric weight or fabric thickness. MONOVA was also used to test Hypotheses 7 and 8 to examine the influences of the antibacterial treatments, laundering cycles, and their interaction on breaking strength loss due to abrasion in the warp direction and in the filling direction. The significant level (*p*-value) was set at .01%. If the means were significantly different (i.e., *p*-value smaller than .01%), the null hypothesis was rejected. If the null hypothesis was rejected, the Tukey's Honestly Significant Difference Test, one type of post hoc test, was used to perform multiple comparisons between group means.

Table 2: Means of the percentage reduction of antibacterial properties against *S. aureus* in each experimental cell

LAUNDERING CYCLES	AVERAGE % REDUCTION (*S. aureus*)		
	AMS	PHMB	NO TREATMENT
0			
5			
10			
25			

Table 3: Means of the percentage reduction of antibacterial properties against *K. pneumoniae* in each experimental cell

LAUNDERING CYCLES	AVERAGE % REDUCTION (*K. pneumoniae*)		
	AMS	PHMB	NO TREATMENT
0			
5			
10			
25			

CHAPTER IV

RESULTS

This chapter is organized in four sections. The first section contains results from the scanning electron microscopy (SEM) micrographs and the acid dye test, which are presented as a means of qualitative examination on the proper application of the finishes. The second section contains the results from the analyses of antibacterial properties, which includes the examinations of the influences of treatments and laundering cycles on the antibacterial properties. The third and fourth sections contain the results from the analyses of the fabric descriptive and strength properties of the specimens, respectively.

RESULTS FROM THE SEM AND ACID DYE EXAMINATIONS

The purpose of using SEM is to examine if the treatment finishes were applied successfully on the test fabrics. An ISI SX-40 scanning electron microscope was used to project an image of each specimen (i.e., with AMS, with PHMB, no treatment) to examine visually any differences in the specimen surface, across the three fabrics. If the finishes are evenly applied on the fabric surface through treatment, the fabric surface of specimens with either treatment is expected to be smoother and more uniform than the untreated fabric surface. In preparation for the tests, the specimens were secured using a conductive pressure sensitive adhesive and were sputtered with a gold coating to secure a proper image. The results, from examining nine

specimens, showed that there was a visual difference between the fabric surfaces of the treated and untreated specimens. At 1000x magnification, surfaces of specimens treated with either AMS or PHMB looked very smooth and uniform (see Figures 13 and 14 respectively). Upon visual examination, the specimen with no treatment showed unevenness and cracks on its surface (see Figure 15). The visual examination of the SEM micrographs indicated that the antibacterial treatments were applied successfully to each test fabric.

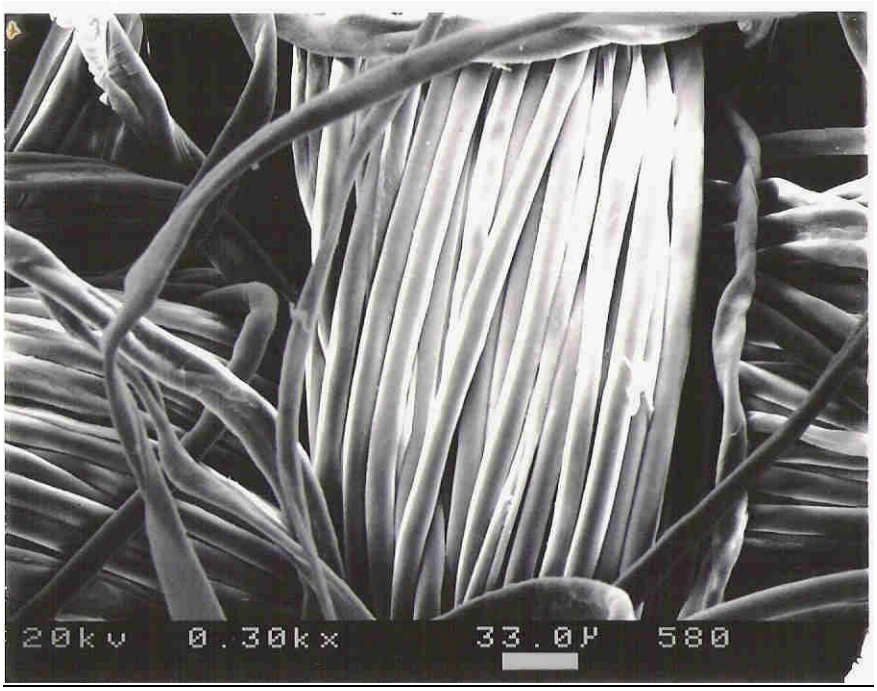

Figure 13. SEM micrograph of AMS treated specimen.

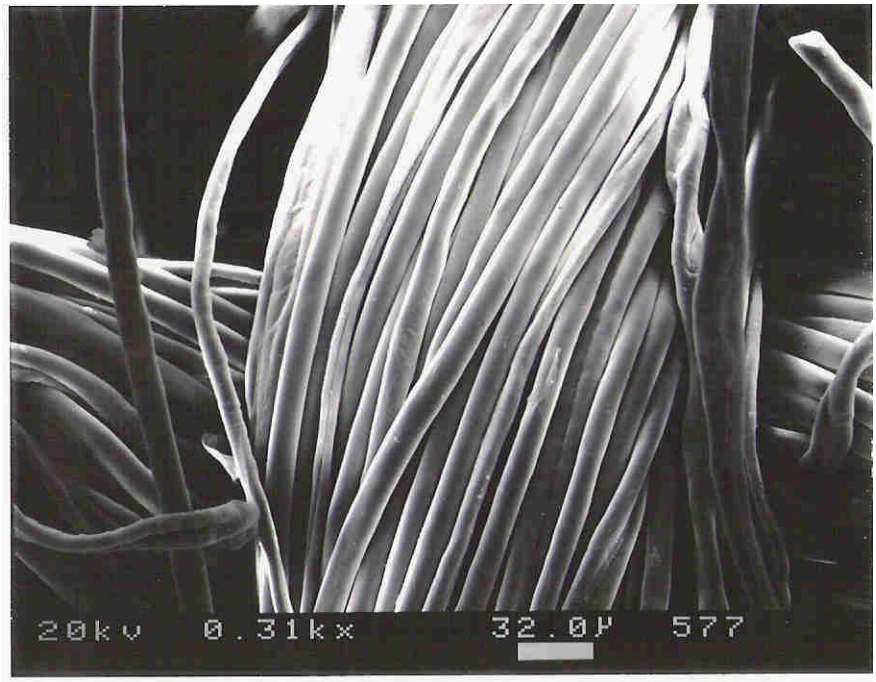

Figure 14. SEM micrograph of PHMB treated specimen.

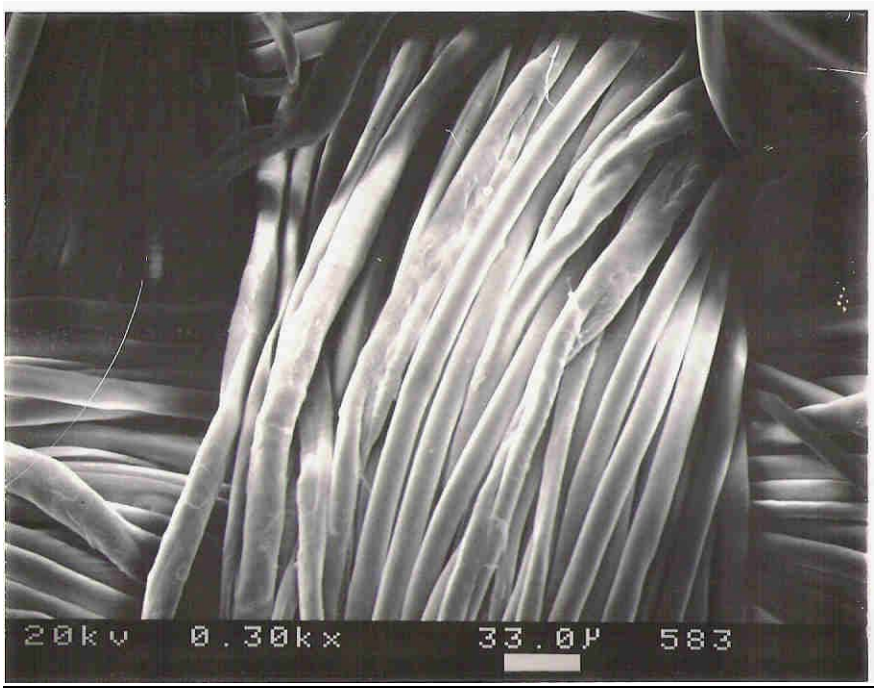

Figure 15. SEM micrograph of no treatment specimen.

The acid dye test was another qualitative method used to confirm the successful application of the antibacterial compounds on the fabric. One test fabric from each treatment group (i.e., AMS, PHMB, no treatment) was randomly selected and used to represent each treatment test fabric for the acid dye test. A 1 x 1 inch square specimen was cut from each of the randomly selected treatment fabrics and placed in a 3% acid blue dye solution (i.e., DyStar, Telon A). One drop of acetic acid was added in the dye solutions to activate the dye for the treated specimen to absorb the dye. The blue acid dye solution was then poured in silver canisters and placed on the LABOMAT at 100°C for 30 minutes. If the dye solution turned blue, it indicated that the antibacterial agents were applied successfully to the fabric. The color change occurs because, if there was a layer of finish on the fabric, the dye would adhere to the finish resulting in a blue stain on the fabric surface. The results from the acid dye tests showed that AMS and PHMB specimens had a blue dye stain on their surfaces, which indicated that the antibacterial finishes were successfully applied to the fabric. The no treatment specimen remained unstained, indicating no reactive finish adhering to the surface.

ANALYSES OF ANTIBACTERIAL PROPERTY

ANTIBACTERIAL TESTING

The main purpose of this research was to examine whether antibacterial finishes could effectively reduce the presence of bacteria that have the potential of penetration and transmission on fabrics used for healthcare workers uniforms (HCWU). Antibacterial testing was done to the three sets of fabric samples to determine the effectiveness of the finishes. The antibacterial test results were first reported by Avecia Microbiocides, the company that conducted the antibacterial testing, in log reductions of the bacteria. The testing company then converted the log reductions

into percentage reduction in the following ratios: 1 log reduction equals to 90% reduction, 2 log reduction equals to 99% reduction, 3 log reduction equals to 99.9% reduction, and 4 log reduction equals to 99.99% reduction. A log reduction of 4 is considered to be excellent antibacterial properties. This high level of reduction is preferred for healthcare workers (HCW) because they are constantly surrounded by the exposure of harmful bacteria (J. Rajan, personal communication, 2003).

DATA ANALYSES OF ANTIBACTERIAL PROPERTIES

The results from the Hotelling's Trace test, one of the Multivariate Analysis of Variance (MANOVA) was performed on the data from the antibacterial tests from the three fabrics and indicated that the influences of treatment, laundering, and the interaction between the two independent variables on the antibacterial activities were significant (F=34471.40, p<.001). Further analyses of between subject effects indicated that the influences were significant for both *S. aureus* (F=1529.13, p<.001) and *K. pneumoniae* (F=8416.96, p<.001) (see Table 4).

Table 4. Effects of treatments and laundering cycles on antibacterial properties against *S. aureus* and *K. pneumoniae*.

Variable	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square	F
Main Effect	82.10 [1]	11	7.45	1529.13*
	58.38 [2]	11	5.31	8416.96*
Treatments (T)	75.15 [1]	2	37.58	7698.57*
	41.42 [2]	2	20.71	32846.66*
Laundering Cycles (LC)	4.04 [1]	3	1.35	275.73*
	9.94 [2]	3	3.31	5256.16*
T x LC	2.91 [1]	6	.49	99.35*
	7.02 [2]	6	1.17	1854.12*
Residual	.12 [1]	24		
	.02 [2]	24		
Total	147.94 [1]	36		
	58.40 [2]	36		

* $p < .001$ [1]*S. aureus* [2]*K. pneumoniae*

When the effect of treatments was examined, the log reductions of the antibacterial properties between treatments were significantly different for both *S. aureus* (F=7698.57, p<.001) and *K. pneumoniae* (F=32846.66, p<.001) (see Table 4). The means of the log reduction of antibacterial properties of the no treatment specimens, AMS treated specimens, and PHMB treated specimens against *S. aureus* were 3.77 x 10^{-6}, .70, and 3.35, respectively, and against *K. pneumoniae* were 5.10 x 10^{-6}, .51, and 4.29 respectively. The Tukey Honestly Significance Difference Tests (THSDT), post hoc analyses, were conducted, and the results showed that the influences of the treatments (i.e., AMS, PHMB, no treatment) were significantly different from one another for both *S. aureus* and *K. pneumoniae* at .001 significance level. AMS and PHMB treated specimens had a significantly higher reduction than the no treatment specimens, and

PHMB treated specimens had a significantly higher reduction than AMS treated specimens for both bacteria. Based on these results, Hypothesis 1 was rejected. There were significant differences in antibacterial activities among three treatments (i.e., AMS, PHMB, no treatment) against *S. aureus* and *K. pneumoniae*.

The influence of laundering on antibacterial properties was also significant for both *S. aureus* and *K. pneumoniae* (F=275.73, p<.001; F=5256.16, p<.001, respectively) (see Table 4). The means of the log reduction of antibacterial properties against *S. aureus* at 0, 5, 10, and 25 laundering cycles were 1.89, 1.26, 1.28, and 0.98 correspondingly. THSDT showed that the log reductions against *S. aureus* were significantly different between the laundry cycles of before laundering and after five laundering cycles. This result might be due to the initial loss of finish in the early washings that produced a lower log reduction of *S. aureus* after laundering. Between five and ten laundering cycles, the log reductions against *S. aureus* were not significantly different. This result suggested that additional washing beyond the five cycles, up to and including ten cycles had no significant effect on the finish as indicated by similar log reductions against *S. aureus*. However, between 10 and 25 laundering cycles, the log reductions against *S. aureus* were significantly different, again. Although a progressive loss was found across two levels, the pattern of the log reductions indicated the possibility of levels of washing thresholds with various numbers of laundry cycles, instead of a progressive loss. Future study with more levels of washing would be needed to predict an exact pattern.

The means of the log reduction of antibacterial properties against *K. pneumoniae* at 0, 5, 10, and 25 laundering cycles were 1.85, .90, .84, and .41 respectively. THSDT showed that the log reduction against *K. pneumoniae* at each laundering cycle was significantly different from one another, which indicated that as the laundering cycles increased, the log reduction against *K.*

pneumoniae significantly decreased. A significant interaction of treatments and laundering cycles was found for both *S. aureus* (F=99.35, p<.001) and *K. pneumoniae* (F=1854.12, p<.001) (see Table 4). The results indicated that the influences of the treatments on antibacterial activities were different in various laundering cycles. Based on these results, Hypothesis 2 was rejected. There were significant differences among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on antibacterial activities against *S. aureus* and *K. pneumoniae*.

Because a significant interaction between treatments and laundering cycles was found, a series of one-way Analysis of Variance (ANOVA) were conducted to examine differences of treatments in the log reduction against *S. aureus* and *K. pneumoniae* for each laundering cycle. The results showed that the log reductions against *S. aureus* between treatments were significantly different at each selected laundering cycle (see Table 5). The results from the THSDT indicated that for the before laundering and after five laundering cycles, the log reductions against *S. aureus* among AMS, PHMB, and no treatment specimens were significantly different. PHMB treated specimens had significantly better log reduction than AMS treated specimens, and AMS treated specimens had significantly larger reduction than the no treatment specimens. After 10 laundering cycles, PHMB had consistently larger reductions than both AMS and no treatment specimens. However, there were no significant difference in the amount of reduction against *S. aureus* between AMS and no treatment specimens.

Table 5. Effects of treatments on antibacterial properties against *S. aureus* in each laundering cycle.

Laundering Cycles	Mean of Log Reduction S. aureus			
	No treatment	AMS	PHMB	*F*
0	3.60×10^{-6} [a]	1.18 [b]	4.50 [c]	4757.00*
5	3.12×10^{-6} [a]	.72 [b]	3.12 [c]	9811.27*
10	3.80×10^{-6} [a]	.67 [a]	3.09 [b]	592.49*
25	3.97×10^{-6} [a]	.22 [a]	2.71 [b]	3603.93*

[a,b,c] In the same row, means with different superscript letters are significantly different at .001 level by THSDT.
*p<.001

Table 6 reported the percent reductions against *S aureus* that were converted from the mean log reductions, in which 1 log reduction equals to 90% reduction, 2 log reduction equals to 99% reduction, 3 log reduction equals to 99.9% reduction, and 4 log reduction equals to 99.99% reduction. The results showed that PHMB consistently had over 99% reduction against *S. aureus* before laundering and even after 25 laundering cycles. AMS had 90% reduction against *S. aureus* before laundering; however, the log reduction was significantly reduced after laundering and almost totally diminished at 25 laundering cycles. The no treatment specimen showed no reduction in antibacterial activities either before or after laundering.

Table 6. Means of the percentage reduction of antibacterial properties against *S. aureus* in each experimental cell

Laundering Cycles	Average % Reduction *S. aureus*		
	No Treatment	AMS	PHMB
0	NR	90	99.99
5	NR	<90	99.9
10	NR	<90	99.9
25	NR	<90	99

Note: NR = no reduction

Figure 16 shows a visual comparison of the antibacterial properties against *S. aureus* in relation to the number of launderings for the three fabrics. The plot highlights the results that the PHMB treated specimens had higher reduction activities against *S. aureus* than AMS treated specimens before laundering and throughout all 25 laundering cycles.

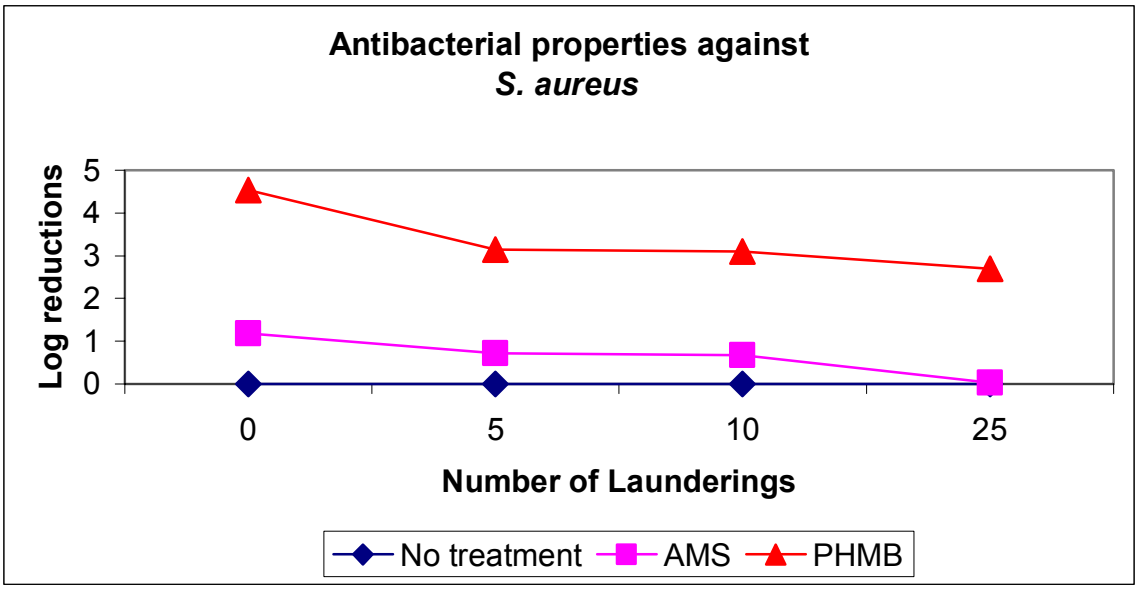

Figure 16. Antibacterial activities of each treatment and laundering cycle against *S. aureus*.

Regarding the antibacterial activities against *K. pneumoniae*, the results from the series of one-way ANOVAs showed that the log reductions against *K. pneumoniae* between the treatments were significantly different at each laundering cycle (see Table 7). THSDT indicated that the amount of reduction between treatments was significantly different from one another before laundering. PHMB had a larger log reduction than AMS against *K. pneumoniae*, and AMS had a larger reduction than the no treatment specimen. However after laundering, there were no significant differences between AMS and the no treatment specimens although PHMB treated specimens continued to have a higher log reduction than both AMS and the no treatment specimens.

Table 7. Effects of treatments on antibacterial property against *K. pneumoniae* in each laundering cycle.

Laundering Cycles	Mean of Antibacterial Property *K. pneumoniae*			
	No treatment	AMS	PHMB	*F*
0	5.12×10^{-6} [a]	1.98 [b]	3.57 [c]	6339.19*
5	4.00×10^{-5} [a]	.05 [a]	2.65 [b]	22962.35*
10	4.50×10^{-5} [a]	.01 [a]	2.50 [b]	9203.43*
25	6.77×10^{-5} [a]	.00 [a]	1.23 [b]	45384.50*

[a,b,c] In the same row, means with different superscript letters are significantly different at .001 level by THSDT.
* $p < .001$

Table 8 reported the percent reduction of each treatment against *K. pneumoniae.* The results reported that PHMB had the higher percent reduction of 99.9% than AMS and the no treated specimens before laundering. After laundering, PHMB had at least 90% reduction through 25 laundering cycles. Although AMS treated specimens initially had about a 99% reduction; its effectiveness was diminished significantly after laundering. As expected, the no treatment specimen showed no antibacterial activities against *K. pneumoniae* either before or after laundering.

Table 8. Means of the percentage reduction of antibacterial properties against *K. pneumoniae* in each experimental cell

Laundering Cycles	Average % Reduction *K. pneumoniae*		
	No Treatment	AMS	PHMB
0	NR	~ 99	99.9
5	NR	<90	99
10	NR	<90	99
25	NR	<90	90

Note: NR = no reduction

Figure 17 shows a visual comparison of the antibacterial properties against *K. pneumoniae* in relation to the number of launderings for the three fabrics. The plot highlights the results that

showed PHMB treated specimens had better antibacterial properties than AMS treated specimens against *K. pneumoniae* throughout each cycle.

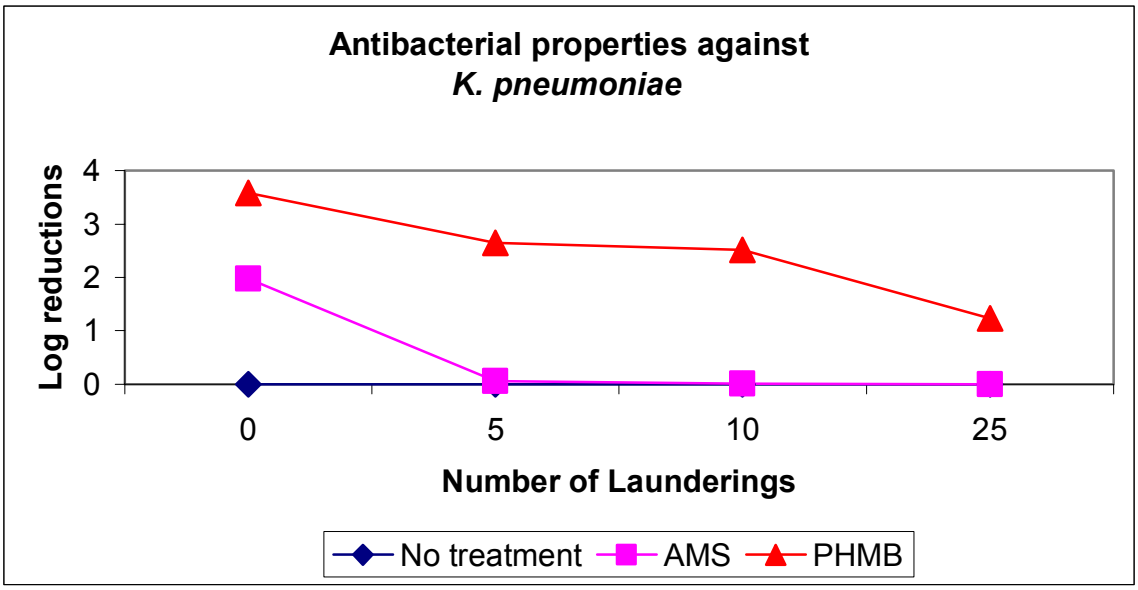

Figure 17. Antibacterial activities of each treatment and laundering cycle against *K. pneumoniae*

ANALYSES OF FABRIC DESCRIPTIVE AND STRENGTH PROPERTIES

Results for the influences of antibacterial treatment and laundering on the fabric descriptive properties (i.e., fabric weight, fabric thickness) and breaking strength property are discussed in the following sections.

DESCRIPTIVE PROPERTIES

The two-way analyses of variance (ANOVAs) were conducted to determine the influences of the treatment (i.e., AMS, PHMB, no treatment), laundering cycles (i.e., 0, 5, 10, 25), and the interactions between the treatments and launderings on fabric weight and on fabric thickness.

Fabric Weight

Fabric weight was measured using a Denver Mettler balance according to the ASTM D 3776-96 Standard Test Method for Mass per Unit Area (Weight) of Woven Fabric, Option C - Small Swatch of Fabric. The weight was reported in grams per meter squared (g/m^2). The results from the two-way ANOVA indicated that the influences of treatment, laundering, and the interaction between the two independent variables on fabric weight were significant (F=120.18, p<.001) (see Table 9). Further examination with the univariance F test showed that the influence of treatment on fabric weight was significant (F=163.29, p<.001). The means of the fabric weight for AMS, PHMB, and no treatment specimens were 103.49g/m^2, 103.94g/m^2, and 97.28g/m^2 respectively. The THSDT post hoc analysis was conducted, and the results showed that the fabric weight of the specimens treated with AMS and PHMB were significantly heavier than the no treatment specimen at .001 significance level. Treated specimens were heavier than the untreated specimens**.** Based on these results, Hypothesis 1 was rejected. There was a significant difference in fabric weight among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment). Although significant statistically, the amount of weight difference may or may not be important to the end user. Increased fabric weight could be interpreted as bulky or as "substantial" by various end users. User perception of this difference is suggested for future

Table 9. Effects of treatments and laundering cycles on fabric weight.

Variable	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square	F
Main Effect	2243.16	11	203.92	120.18*
Treatments (T)	554.16	2	277.08	163.29*
Laundering Cycles (LC)	1262.05	3	420.68	247.92*
T x LC	71.154	6	71.15	41.93*
Residual	81.45	48	1.70	
Total	2324.58	60		

*$p < .001$

The influence of laundering on fabric weight was also significant (F=247.92, p<.001). The means at 0, 5, 10, and 25 laundering cycles were 104.28g/m^2, 107.44g/m^2, 98.93g/m^2, and 95.63g/m^2 respectively. THSDT showed that the fabric weight for each laundering cycle was significantly different from one another at the .001 significance level.

A significant interaction between treatments and laundering cycles was found (F=41.93, p<.001) (see Table 9). The results indicated that the influences of treatments on fabric weight were different at various laundering cycles. Based on these results, Hypothesis 4 was rejected. There were significant differences among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on fabric weight.

Because a significant interaction between treatments and laundering cycles was found, a series of one-way ANOVAs were conducted to examine the difference among treatments on

fabric weight for each laundering cycle. The one-way ANOVA showed that the fabric weights of AMS, PHMB, and no treatment specimens were significantly different before laundering and at five laundering cycles (see Table 10). The results from THSDT showed that before laundering, the mean fabric weight of the AMS and PHMB treated specimens were significantly heavier than the mean fabric weight of the no treatment specimens. At five laundering cycles, PHMB treated specimens was significantly heavier than both AMS and no treatment specimens. At 10 and 25 laundering cycles, AMS, PHMB, and no treatment specimens were not significantly different from one another.

Table 10. Effects of treatments on fabric weight in each laundering cycle.

Laundering Cycles	**Mean of Fabric Weight (g/m^2)**			
	No treatment	**AMS**	**PHMB**	***F***
0	96.87 [a]	107.97 [b]	108.00 [b]	332.15**
5	98.42 [a]	105.06 [a]	112.49 [b]	15.17*
10	98.57 [a]	99.93 [a]	98.28 [a]	1.29
25	94.69 [a]	95.64 [a]	96.54 [a]	6.91

[a,b] In the same row, means with different superscript letters are significantly different at .001 level by THSDT.
*p< .01, **p< .001

Fabric Thickness

Fabric thickness was measured according to the ASTM D 1777-96 Standard Test Method for Thickness of Textile Materials. The same specimen used to test the fabric weight was also used to test fabric thickness. Fabric thickness was measured to the nearest 0.001". The results from the two-way ANOVA indicated that the influences of treatment, laundering, and the interaction between the two independent variables on fabric thickness were significant (F=23.19, p<.001) (see Table 11). Further variance F test showed that the influence of treatment on fabric

thickness was significant (F=6.18, p<.01). The means of the fabric thickness for AMS, PHMB, and no treatment were .0120", .0125", and .0130" respectively. The THSDT post hoc analysis was conducted, and the results showed that the fabric thickness of the specimens treated either with AMS or with PHMB were significantly thinner that the no treatment specimen at .01 significance level. Based on these results, Hypothesis 5 was rejected. There were significant differences in fabric thickness among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment).

Table 11. Effects of treatments and laundering cycles on fabric thickness

Variable	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square	F
Main Effect	4.14×10^{-5}	11	3.77×10^{-6}	23.19**
Treatments (T)	2.01×10^{-6}	2	1.00×10^{-6}	6.18*
Laundering Cycles (LC)	1.64×10^{-5}	3	5.45×10^{-6}	33.53**
T x LC	2.31×10^{-5}	6	3.85×10^{-6}	23.68**
Residual	7.80×10^{-6}	48	1.63×10^{-7}	
Total	.009	60		

*p<.01 **p<.001

The influence of laundering on fabric thickness was also significant (F=33.53, p<.001). THSDT showed that fabric thickness before laundering was significantly thinner than fabric thickness after laundering. However, there were no significant differences in fabric thickness at 5, 10, and 25 laundering cycles at .001 significant level, and the means at those laundering cycles were .0110, .0130, .0130, and .0120 respectively.

A significant interaction among treatments and laundering cycles was found (F=23.68, p<.001). The results indicated that the influences of treatments on fabric thickness were different in various laundering cycles. Based on this result, Hypothesis 6 was rejected. There were significant differences among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on fabric thickness.

Because a significant interaction between treatments and laundering cycles was found, a series of one-way ANOVAs were conducted to examine the difference among treatments on fabric thickness for each laundering cycle. The one-way ANOVA showed that there were no significant differences in fabric thickness between the treatments before laundering, and at 5 and 10 laundering cycles; however, at the 25 laundering cycles there was a significant difference between no treatment and AMS and no treatment and PHMB treated specimens at the .001 significance level (see Table 12). The no treatment specimen was thicker than both AMS and PHMB treated specimens at 25 laundering cycles.

Table 12. Effects of treatments on fabric thickness in each laundering cycle.

Laundering Cycles	**Mean of Fabric Thickness (inch)**			
	No treatment	**AMS**	**PHMB**	**F**
0	.0110 [a]	.0118 [a]	.0116 [a]	5.20
5	.0122 [a]	.0130 [a]	.0132 [a]	15.27
10	.0132 [a]	.0124 [a]	.0124 [a]	5.82
25	.0140 [a]	.0116 [b]	.0117 [b]	44.24*

[a,b] In the same row, means with different superscript letters are significantly different at .001 level by THSDT.
* $p < .001$

STRENGTH PROPERTIES

Breaking strength was measured according to the ASTM D 5034 Test for Breaking Force and Elongation of Textile Fabrics (Grab Test). The test was reported in strength loss before and after abrasion. The abraded fabric was measured according to the AATCC Test Method 93 Abrasion Resistance for Fabrics: Accerlerotor Method. At 25 laundering cycles, the abraded specimens treated with AMS, PHMB, and no treatment were all torn; therefore, the percentage of strength loss of all specimens was considered as 100%. The results from the Hotelling's Trace test, one of the MANOVA tests, indicated that the influences of treatment, laundering, and the interaction between the two independent variables on the breaking strength loss due to abrasion were significant (F=8716.37, p=.001). Further analysis of between subjects effects indicated that the influences were significant in both warp (F=1642.93, p<.001) and filling directions (F=2023.94, p<.001) (see Table 13). The univariance F test showed that the influence of treatment on breaking strength loss due to abrasion was not significant for either the warp or filling directions. The means of the strength loss for AMS, PHMB, and no treatment specimens in the warp direction were 28.38%, 27.95%, 28.23% and in the filling direction were 28.39%, 29.25%, and 28.02% respectively. These results showed that there was no significant difference in breaking strength loss between AMS and PHMB treated specimens, and no treatment specimens. Based on these results, Hypothesis 7 was not rejected. There was no significant difference in breaking strength loss due to abrasion among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment) in either the warp direction or the filling direction.

Table 13. Effects of treatments and laundering cycles on breaking strength in the warp and filling directions.

Variable	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square	F
Main Effect	103259.58 [1]	11	9387.23	1642.93*
	102359.63 [2]	11	9305.42	2023.95*
Treatments (T)	1.88 [1]	2	.94	.17
	15.95 [2]	2	7.97	1.73
Laundering Cycles (LC)	103255.42 [1]	3	34418.47	6023.85*
	102322.11 [2]	3	34107.37	7418.41*
T x LC	2.28 [1]	6	.38	.066
	21.57 [2]	6	3.60	.782
Residual	274.26 [1]	48	5.71	
	220.69 [2]	48	4.60	
Total	151197.49 [1]	60		
	151495.60 [2]	60		

*$p < .001$ [1]Warp [2]Filling

The influence of laundering on breaking strength loss was significant at both the warp direction (F=6023.85, p<.001) and the filling direction (F=7418.41, p<.001). The means of the strength loss at 0, 5, 10, and 25 laundering cycles were 2.65%, 3.75%, 6.34%, and 100% respectively. THSDT showed that the breaking strength loss was not significantly different between the treatments before laundering and after five laundering cycles in both the warp and filling directions; however, after five laundering cycles, the strength loss of the fabric increased significantly. The results showed that laundering cycles did significantly influence the strength of the fabric.

No significant interaction of treatments and laundering cycles was found in either the warp or filling direction. Based on this result, Hypothesis 8 was not rejected. There was no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of

three treatments (i.e., AMS, PHMB, no treatment) on breaking strength loss due to abrasion in either the warp direction or the filling direction.

CHAPTER V

HYPOTHESES EXAMINATION, DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

This last chapter is organized into two sections. The first section, hypotheses examination, examines the hypotheses generated in Chapter 1. The second section, discussion and recommendations, discusses the results from the study and provides recommendations for future research.

HYPOTHESES EXAMINATION

The objective of this research is to compare the antibacterial properties, fabric descriptive properties (i.e., fabric weight, fabric thickness), and durability property (i.e., breaking strength loss due to abrasion) of AEGIS Microbe Shield (AMS) and polyhexamethylene biguanide (PHMB) on a 65/35% polyester/cotton blend fabric before and after laundering. Based on the objective of the research, eight hypotheses were generated in Chapter 3 and each hypothesis was examined in the following sections.

H1: There is no significant difference in antibacterial activities among three treatments (i.e., AMS, PHMB, no treatment) against *S. aureus* or *K. pneumoniae*.

Results showed that there were significant differences between specimens with and without treatments for antibacterial properties against both *S. aureus* and *K. pneumoniae*. PHMB treated specimens had the highest reduction against both *S. aureus* and *K. pneumoniae* followed by AMS treated specimens and then no treatment specimens. Based on these results, Hypothesis 1 was rejected because there were significant differences between treatments in antibacterial activities against *S. aureus* and *K. pneumoniae*. The experimental study results provided evidence that the addition of the antibacterial finishes to the fabric specimens is the reason why PHMB and AMS treated specimens had significantly better antibacterial activities than the no treatment specimen.

H2: There is no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on antibacterial activities against *S. aureus* or *K. pneumoniae*.

Results showed that there were significant interactions between treatments and laundering cycles for both *S. aureus* and *K. pneumoniae*, which indicates that there were significant differences among various laundering cycles in the effects of treatments on antibacterial activities against the two bacteria. Based on these results, Hypothesis 2 was rejected. At all four laundering cycles examined, PHMB treated specimens consistently had significantly higher antibacterial reductions than the AMS treated specimens and the no treatment specimens. However, when comparing the results at various laundering cycles, the antibacterial reductions of AMS treated specimens were not always higher than the no treatment specimens. Before laundering and at the fifth laundering cycle, the antibacterial activities of AMS treated specimens were significantly higher against *S.*

aureus than the no treatment specimens; however, for the antibacterial activity against *K. pneumoniae*, the AMS treated specimens were significantly higher than the no treatment specimens only before laundering. At five laundering cycles, there were no significant differences between AMS and the no treatment specimens against *K. pneumoniae*. It is possible that most of the AMS finish had been washed away from AMS treated specimens resulting in a similar amount of reduction against *K. pneumoniae* to that of the no treatment specimen. In addition, Gram-negative bacteria are harder to reduce than Gram-positive bacteria because of the extra cell wall on Gram-negative bacteria (Kaplan, 2000). This is a possible reason why the bacterial reduction of AMS treated specimens against *S. aureus* (i.e., a Gram-positive bacteria) was higher than that against *K. pneumoniae* (i.e., a Gram-negative bacteria) at the fifth laundering cycle. After 10 laundering cycles, there were no significant differences in antibacterial activities of AMS treated specimens against both *S. aureus* and *K. pneumoniae*. These results suggested that after 10 laundering cycles, most of the finish might have been washed away from the AMS treated specimen resulting in a similar amount of reduction against *S. aureus* and *K. pneumoniae* to that of the no treatment specimen.

H3: There is no significant difference in fabric weight among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment).

Results showed that there were significant differences in fabric weight between specimens with and without treatments. Both AMS and PHMB treated specimens were significantly heavier than the no treatment specimen. Based on these results, Hypothesis 3 was rejected because there were significant differences in fabric weight between treatments. A possible reason is the addition of treatments added to the fabrics thus making them heavier.

H4: There is no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on fabric weight.

Results showed that there was a significant interaction between treatments and laundering cycles, which indicates that there was a significant difference among various laundering cycles in the effects of treatments on fabric weight. Based on these results, Hypothesis 4 was rejected. Before laundering, AMS and PHMB treated specimens were significantly heavier than the no treatment specimen possibly due to the addition of the finishes. At the fifth laundering cycle, PHMB treated specimens were significantly heavier than both AMS treated specimens and no treatment specimens possibly due to some of the AMS finish being washed away. At the 10th and 25th laundering cycles, there were no significant differences in weight for AMS, PHMB, and no treatment, which suggested that most of the finishes might have been washed away from AMS and PHMB treated specimens.

H5: There is no significant difference in fabric thickness among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment).

Results showed that there were significant differences in fabric thickness between specimens with and without treatments. Both AMS and PHMB treated specimens were significantly thinner than the no treatment specimen. Based on these results, Hypothesis 5 was rejected because there were significant differences in fabric thickness between treatments.

H6: There is no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on fabric thickness.

Results showed that there was a significant interaction between treatments and laundering cycles for fabric thickness, which indicates that there was a significant difference among various laundering cycles in the effects of treatments on fabric thickness. Based on these results, Hypothesis 6 was rejected. Before laundering, and at the 5th and 10th laundering cycles, there were no significant differences between treatments in fabric thickness. However, after 25 laundering cycles, the no treatment specimen was significantly thicker than both AMS and PHMB treated specimens. The possible reason might be that after 25 laundering cycles, the yarn structure of the no treatment specimens became loose resulting in an increase of thickness. For AMS and PHMB treated specimens, the adhesion between the finish and the fibers might prevent the yarn from becoming loose, resulting in no change in fabric thickness after 25 laundering cycles.

H7: There is no significant difference in breaking strength loss due to abrasion among fabrics treated with three treatments (i.e., AMS, PHMB, no treatment) in the warp direction or filling direction.

Results showed that there were no significant differences among AMS and PHMB treated specimens and the no treatment specimens for breaking strength loss due to abrasion in the warp or filling direction. Based on these results, Hypothesis 7 was not rejected because no significant differences were found. These results indicated that treatments had no significant influence on fabric strength.

H8. There is no significant difference among four selected laundering cycles (i.e., 0, 5, 10, 25) in the effects of three treatments (i.e., AMS, PHMB, no treatment) on breaking strength due to abrasion in the warp direction or filling direction.

Results showed that there was no significant interaction between treatments and laundering cycles in the warp or filling direction, which indicates that there was no significant difference among various laundering cycles in the effects of treatments on breaking strength loss due to abrasion in both directions. Based on these results, Hypothesis 8 was not rejected. At each laundering cycle, the result was the same.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

As stated in Chapter 1, there is a major concern for healthcare workers (HCW) regarding transmission of bacteria to and from their patients. Bacteria have different modes of transports (i.e., air particles, blood, body fluids) that aid in their transmission. The readily available presence of bacteria on healthcare workers uniforms (HCWU) greatly increases the potential for

penetration and transmission of these bacteria. The purpose of this study was to examine whether antibacterial finishes can effectively reduce the presence of bacteria on HCWU, specifically comparing the antibacterial activity of AMS and PHMB treated specimens. The results of the current study showed that adding an antibacterial agent as a finish to HCWU can be an effective way to help combat the problem of the transmission of bacteria. This study found that PHMB treated fabrics are a good candidate for the use of reusable HCWU incurring up to 25 laundering cycles. After 25 laundering cycles, the reduction rate of PHMB remained higher than 99% against *S. aureus* and higher than 90% for *K. pneumoniae*. However, AMS is not as an effective antibacterial agent for reusable HCWU that would incur even a limited number of laundry cycles. Although AMS was effective before laundering, it barely reduced *K. pneumoniae* after five laundering cycles and *S. aureus* after 10 laundering cycles. These results showing that PHMB remained effective after several launderings support the hypothesis of Payne and Kudner (1996**)** proposing that PHMB may have a stronger bond than AMS to cotton fabric because PHMB has multiple cationic groups while AMS has only one cationic group.

This study had similar results in Gram-positive bacterium reduction to the research of Murray et al. (1988) where AMS also inhibited Gram-positive bacterium such as *S. aureus* on unlaundered cotton/polyester fabric. Inconsistently, Murray et al. found that AMS was unable to reduce Gram-negative bacteria such as *E. coli* and *K. pneumoniae*. The current study showed that before laundering, AMS was able to reduce Gram-negative bacteria (i.e., *K. pneumoniae*) close to 99% reduction rate, although the effect was diminished significantly after laundering. The reason for the dissimilarity of the results between Murray et al.'s study and the current study is not clear. Similarly to the current study, Murray et al. examined the antibacterial activities of a cotton/polyester fabric pretreated with AMS; however the amount of the agent used was

proprietary information, and therefore, could not be compared to the current study. White and Gettings (1985) did find a similar result to the current study. AMS could inhibit Gram-negative bacteria; however, the authors tested the AMS agent in solution not on fabric, and therefore, no after-laundering results could be compared.

Malek and Speier (1982) studied the bacterial reduction of AMS before and after laundering and found that AMS reduced both *S. aureus* and *E. coli* on cotton fabric before and after laundering. These results were consistent with the before-laundering results of the current study but inconsistent with the after-laundering results. The current study showed that after laundering, AMS was not able to reduce either Gram-positive or Gram-negative bacteria successfully. However, the specific number of times laundered was not revealed in Malek and Speier's study, and therefore, the after-laundering results of the two studies could not be compared. Similar to the study of Malek and Speier, Burlington Industries and Dow Corning Company (1985) reported that AMS was able to reduce odors from the bacterial reduction of Gram-positive and Gram-negative bacteria found in socks before and after 40 laundering cycles. A possible reason for the inconsistencies in the two studies could be the difference in the fabrics used in the studies. In the current study, 65/35% polyester/cotton woven fabric was used and 75/25% acrylic/nylon knitted socks were used in the other study. The antibacterial effect of AMS may vary in fabrics with different fiber contents and fabric constructions. In addition, the amount of AMS treated on the socks from the Burlington Industries and Dow Corning Company study was not stated; and therefore, the amount used could not be compared to the current study.

Compared to the current results, similar findings regarding the antibacterial effect of PHMB again *S. aureus* were found in the study of Payne and Kudner (1996). The authors studied the effect of PHMB on odor reduction for cotton toweling and found that using 0.2% of PHMB

provided some reduction of *S. aureus* and successfully reduced the odor of cotton toweling. Huang and Leonas (2000) also examined the antibacterial effect of PHMB against *S. aureus* and found that a minimum add-on of 0.75% of PHMB along with a flourochemical finish was able to reduce *S. aureus* on nonwoven fabrics. The current study similarly revealed that PHMB at a 2.3% concentration add-on without any other finish could successful reduction of both *S. aureus and K. pneumoniae* on 65/35% polyester/cotton blend fabrics.

The results of fabric weight and fabric thickness showed that, in addition to reducing *S. aureus* and *K. pneumoniae*, antibacterial finish may bring other benefits to HCWU. Adding a finish to fabric not only makes the fabric heavier but also increases its firmness. If a thin fabric is used, an addition of a finish could help the fabric keep its shape. Adding a finish may also keep the yarn structure from becoming loose during laundering, thus retaining the fabric shape after repeated laundering. This change could improve appearance retention of the fabric through repeated launderings, which might encourage increased wearing of the HCWU. If the stiffness or firmness increased to the point of discomfort for the wearer, additional firmness could result in a negative effect in causing HCW not to wear the item.

Resisting strength loss due to abrasion is also an important fabric property related to antibacterial property. If the HCWU is rubbed against various objects such as an operating table, the fabric with poor abrasion resistance can be abraded thus increasing the possibility of exposure to bacteria. When the breaking strength loss due to abrasion was examined in this study, the results showed that there were no significant differences among the specimens with and without treatments. Adding AMS and PHMB finishes on 65/35% polyester/cotton blend fabric did not influence fabric durability, as measured by breaking strength due to loss of abrasion.

An Internet search conducted by the researcher (see Appendix A) showed that there are no commercially available antibacterial finished HCWU on the market, thus providing an option of using antibacterial agents to treat HCWU could create a niche for companies selling HCWU. The process of applying the antibacterial finish through padding and drying is easy and economical. As stated in Chapter 1, PHMB and AMS are very similar in cost (i.e., $60 for 25 grams). In this study, a 2.3% add-on was used for PHMB versus 0.5% add-on for AMS, which is about five times more agent used on PHMB than AMS, and therefore, making PHMB more expensive. However, PHMB reduced both *S. aureus* and *K. pneumoniae* for up to 25 laundering cycles as compared to AMS, which barely reduced either bacterium after laundering. The maximum concentration was used in the current study. It is possible that a less amount of PHMB is needed to have similar antibacterial functions. A study to determine the minimum amount of finish add-on to the fabric would be beneficial in reducing the cost of using enough antibacterial agents to inhibit a maximum amount of bacteria for HCWU.

The two antibacterial agents (i.e., AMS and PHMB) examined in this research were selected from commercially available agents due to their non-leaching properties. More research, such as developing new agents or making derivatives from commercially available agents to enhance the properties, is recommended to provide HCWU the ability to protect HCW from bacteria in healthcare environments. In this study, one type of Gram-positive bacteria (i.e., *S. aureus*) and one type of Gram-negative bacteria (i.e., *K. pneumoniae*) were examined. However, many forms of bacteria are found in the healthcare environment. More studies are needed to determine how well these antibacterial agents could reduce various microorganisms such as *Candida albicans* and *E. coli*. In addition to various microorganisms, different viruses should also be tested due to an increasing concern among HCW about viral infections such as HIV, AIDS, and Hepatitis.

This research only explored antibacterial agents of AMS and PHMB on reusable HCWU. These two types of antibacterial agents may have different activities on disposable materials. A similar experimental design is suggested to be conducted to investigate the antibacterial activity of AMS and PHMB on nonwoven gown materials. In addition, other materials used to make reusable gowns such as 100% cotton could be studied because they are also often used for HCWU. Gruendemann and Mangum (1999) suggested that a reusable gown should be able to withstand approximately 75 laundering cycles before deterioration of the finish is detectable. In this study, only up to 25 laundering cycles were tested. Longer laundering cycles are suggested to be evaluated in future research because longer laundering cycles for reusable HCWU can be beneficial economically. According to DiGiacomo et al. (1992), washing reusable gown costs less than using disposable gowns. In addition, a variety of laundering detergents can be examined including commercial detergents. In this study, AMS and PHMB treated specimens were examined and compared on four properties (i.e., antibacterial, fabric weight, fabric thickness, breaking strength loss due to abrasion); however, other properties**,** such as comfort should be evaluated to provide a more comprehensive view of the HCWU and the wearability of the item. A balance of heat produced by the body relative to changes in environmental conditions is needed in order to achieve comfort (McCullough, 1993). Comfort properties such as moisture transmission, heat transmission resistance, and air permeability are important for HCWU (Byrne, et al., 2000) because studies have shown if a worker is uncomfortable in their uniform, they are more likely not to wear it properly (Hoagland & Maurice, 2000; Smith, 1986).

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APPENDICES

Appendix A. Internet Search of Antimicrobial Uniforms

Manufacturers	Antimicrobial Finished Uniforms (Y/yes, N/No)
Crest	N
Peaches	N
White Swan	N
Med Gear	N
White Cross	N
PL of California	N
Caduceus	N
Cherokee	N
Barco	N
Disney	N
Scrub by Design	N
Premier	N
AllHeart	N
G.A.L.S. of California	N
ScrubMate	N
Life Uniform	N
L.A. Rose	N
Jasco	N
Graves	N
Scrubs-R-Us	N

Appendix B: Coding System of the Cutting Plan for Pre-Laundering

A.0.1	A.25.2
A.5.1	A.10.2
A.10.1	A.5.2
A.25.1	A.0.2
A.0.3	A.25.4
A.5.3	A.10.4
A.10.3	A.5.4
A.25.3	A.0.4
A.0.5	
A.5.5	
A.10.5	
A.25.5	

P.0.1	P.25.2
P.5.1	P.10.2
P.10.1	P.5.2
P.25.1	P.0.2
P.0.3	P.25.4
P.5.3	P.10.4
P.10.3	P.5.4
P.25.3	P.0.4
P.0.5	
P.5.5	
P.10.5	
P.25.5	

N.0.1
N.5.1
N.10.1
N.25.1

N.25.2
N.10.2
N.5.2
N.0.2

N.0.3
N.5.3
N.10.3
N.25.3

N.25.4
N.10.4
N.5.4
N.0.4

N.0.5
N.5.5
N.10.5
N.25.5