ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

DEVELOPMENT OF NOVEL ELASTOMERIC FABRICS FOR BURN PRESSURE GARMENTS USING VARIOUS ANTIMICROBIAL TECHNOLOGIES

Ph.D. THESIS

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Department of Textile Engineering

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

YANIK YARALANMALARINDA KULLANILAN BASINÇLI GİYSİLER İÇİN ÇEŞİTLİ ANTİMİKROBİYEL TEKNOLOJİLER KULLANILARAK YENİ ELASTOMERİK KUMAŞLARIN GELİŞTİRİLMESİ

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To my beloved family,

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May 2012

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ABBREVIATIONS

At%	: Atomic Percent
C	: Circumference of the limb in cm
FTIR	: Fourier Transform Infrared Spectroscopy
FWHM	: Full Width Half Maximum (High Energy Resolution)
P	: Pressure
PHMB	: Polyhexamethylene Biguanide
Pos	: Binding Energy in eV
QAC	: Quaternary Ammonium Compounds
R	: Radius of the Leg in cm
SEM	: Scanning Electron Microscopy
T	: Tension (kgf)
XPS	: X-Ray Photoelectron Spectroscopy

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LIST OF SYMBOLS

Ag	: Silver
AgCl	: Silver Chloride
$AgNO_3$	: Silver Nitrate
C	: Carbon
F	: Fluorine
mmHg	: milimetre of mercury
N	: Nitrogen
O	: Oxygen
pH	: Power of Hydrogen
Si	: Silicium
α	: Proportionality Coefficient
ε	: Fabric Porosity

DEVELOPMENT OF NOVEL BURN PRESSURE GARMENTS USING VARIOUS ANTIMICROBIAL TECHNOLOGIES TO IMPROVE THE REHABILITATION PERFORMANCES

SUMMARY

In burn treatments, microorganisms on pressure garments during pressure therapy can prevent rehabilitation by causing functional, hygienic and aesthetic difficulties. As bacteria are the most trouble-causing organisms, they can threaten patients causing infection during the long period of use of these garments. In this study, novel burn pressure garments having durable antimicrobial property were developed using various antimicrobial agent procedures on highly elastic Nylon 6.6/ Spandex fabrics in powernet, flat warp and weft knitted structures. Six different antimicrobial agent procedures were used following Quat-Silane, Triclosan, polyhexamethylene biguanide (PHMB) and three different silver-based antimicrobial chemical agents. Untreated, treated and a duplicate treated set of samples washed for 5, 10 and 50 cycles were tested to determine the antimicrobial activity. Three different types of pressure garments were designed including the area from ankle to knee before and after treatments using a mannequin. Commercial wireless pressure sensors were used to control the pressures of burn pressure garments at an acceptable medical range before and after antimicrobial treatments. XPS, SEM and FTIR analysis were conducted to examine the achievement of the treatments using antimicrobial chemical agents on fabric samples. Physical properties were tested in terms of air permeability, stiffness (CD, MD), bursting strength, drapeability, time dependent fabric growth and porosity in order to evaluate the wear performances of burn pressure garments before and after antimicrobial treatments. Thermophysiological properties were tested in terms of thermal resistance (R_{ct}) and isolation properties (clo unit) in order to evaluate the comfort performances of burn pressure garments before and after antimicrobial treatments. The results for bacterial reductions for each antimicrobial agent procedure were satisfying for fabric samples. A small significant decrease in antimicrobial activity was observed even after 50 launderings. A small significant decrease was observed for air permeability, bursting strength and drapeability while a small significant increase was observed for stiffness (CD, MD), thermal resistance (R_{ct}), isolation properties (clo unit) and fabric growth. Porosity values were found not any different for control and treated samples. These results show that after antimicrobial treatments, the fabric samples can provide comfort by providing microclimate and preventing excess sweating of patients. This will help to provide a hygienic environment during wound healing stage by eliminating allergic reactions which will help to prevent the risk of infection. will prevent odor, decrease infection and support reducing of scarring by increasing the rehabilitation rates.

İYİLEŞTİRME PERFORMANSLARININ GELİŞTİRİLMESİ İÇİN ÇEŞİTLİ ANTİMİKROBİYEL TEKNOLOJİLER KULLANILARAK YANIK YARALANMALARINDA KULLANILAN YENİ BASINÇLI GİYSİLERİN GELİŞTİRİLMESİ

ÖZET

Yanık tedavilerinde, bası tedavisi süresince basınçlı giysiler üzerindeki mikroorganizmalar, fonksiyonel, hijyenik ve estetik zorluklara neden olarak rehabilitasyonu önleyebilir. Bakteriler en çok rahatsız edici organizmalardan biri olduğundan, bu giysilerin uzun bir süre kullanımları süresince enfeksiyona neden olarak hastaların yaşamını tehdit edebilir. Bu çalışmada, powernet, düz çözgülü örme ve atkılı örme yapılarda yüksek elastanlı Nylon 6.6/Spandex kumaşlara çeşitli tipte antimikrobiyel kimyasal yöntemler kullanılarak kalıcı antimikrobiyel özelliğe sahip yanık yaralanmalarında kullanılan yeni basınçlı giysiler geliştirilmiştir. Quat-Silane, Triclosan, PHMB (polyhexamethylenebiguanide) ve üç farklı tipte gümüş bazlı antimikrobiyel kimyasal materyal olmak üzere altı farklı antimikrobiyel kimyasal yöntem kullanılmıştır. Antimikrobiyel işlem görmemiş, işlem görmüş ve işlem gördükten sonra 5,10 ve 50 yıkamaya tabi tutulmuş numuneler antimikrobiyel aktiviteyi belirlemek için test edilmiştir. Antimikrobiyel işlemlerden önce ve sonra olmak üzere prototif manken kullanılarak ayak bileğinden dize kadar olan bacak bölgesi olmak üzere üç farklı tipte basınçlı giysi dizaynı gerçekleştirilmiştir. Yanık yaralanmalarında kullanılan basınçlı giysilerin uyguladığı basınçları istenilen medikal aralıkta kontrol edebilmek için, antimikrobiyel işlemlerden önce ve sonra ticari kablosuz basınç sensörleri kullanılmıştır. Kumaş numuneleri üzerinde antimikrobiyel kimyasalların kullanıldığı bitim işlemlerinin başarısını incelemek için XPS, SEM ve FTIR analizleri gerçekleştirilmiştir. Antimikrobiyel işlemlerden önce ve sonra yanık yaralanmalarında kullanılan basınçlı giysilerin giyim performanslarını değerlendirebilmek için fiziksel özellikler hava geçirgenliği, rijitlik (CD,MD), patlama mukavemeti, dökümlülük, zamana bağlı kumaş genişlemesi ve gözeneklilik değerleri açısından test edilmiştir. Antikrobiyel işlemlerden önce ve sonra yanık yaralanmalarında kullanılan basınçlı giysilerin komfor performanslarını değerlendirebilmek için termofizyolojik özellikler termal direnç (R_{ct}) ve izolasyon özellikleri (clo unit) açısından test edilmiştir.

Sonuçlar göstermiştir ki, bu giysilerin ana fonksiyonu olan basınçlarını kontrol ederek çeşitli antimikrobiyel kimyasal prosedür ile memnun edici kalıcı antmikrobiyel aktivite elde edilmiştir. Hava geçirgenliği, patlama mukavemeti ve

dökümlülük değerlerinde çok az bir düşüş gözlemlenirken, rijitlik (CD,MD), termal direnç (R_{ct}) ve izolasyon (clo unit) değerlerinde çok az bir artış gözlemlenmiştir. Bu sonuçlar göstermektedir ki bu yeni yanık yaralanmalarında kullanılan basınçlı giysiler kokuyu önleyecek, enfeksiyonu azaltacak ve rehabilitasyon hızını arttırarak skar doku oluşumunun azaltılmasına destek sağlayacaktır.

Çalışmanın ana amacının farkında olarak çeşitli antimikrobiyel mekanizmalarının yanık yaralanmalarının rehabilitasyonunda kullanılan üç farklı tipte kumaş yapısının basınç davranışlarına ve kimyasal, fiziksel ve mekanik ve komfor özelliklerini ne şekilde etkilediğini anlamak ve araştırmak da çalışmanın diğer amaçları arasında yer almaktadır. Böylece, beş ana amaç belirlenmiş ve şu şekilde tanımlanmıştır.

Bunlardan birisi, altı farklı antimikrobiyel işlemin çeşitli tipte nylon6.6/spandex kumaşların kimyasal özelliklerine etkisini incelemek ve araştırmaktır. Bunun için çeşitli tipte tekstil yapılarındaki lifler üzerindeki değişiklikleri incelemek ve araştırmak için tarama elektron mikroskobu (SEM) kullanılarak yüzey morfolojisi çalışılmıştır. Fourier transform kızılötesi spektroskopisi (FTIR) kullanılarak liflerin kimyasal yapısındaki değişiklikler incelenmiştir. Çeşitli tipte gümüş antimikrobiyel kimyasal maddenin kullanıldığı antimikrobiyel işlemlerin yüzey kimyası, X-ışını fotoelektron spektroskopisi (XPS) kullanılarak çalışılmıştır.

Bu amaçlardan bir diğeri, altı farklı antimikrobiyel işlemin çeşitli tipte nylon6.6/spandex kumaşların antimikrobiyel aktivite dayanımları üzerine etkisini incelemektir. Bunun için altı farklı antimikrobiyel işlemin antimikrobiyel aktivite üzerindeki rölatif dayanımlarını değerlendirebilmek için devirli yıkama testlerinin etkisi çalışılmıştır. Altı farklı antimikrobiyel işlem görmüş üç farklı kumaş tipi ve işlem görmemiş üç farklı kumaş tipi üzerindeki antimikrobiyel aktivite dayanımları birbirleriyle karşılaştırılmıştır.

Bu çalışmada belirlenen diğer bir amaç, üç farklı tipte nylon6.6/spandex kumaş ve altı farklı antimikrobiyel mekanizmanın kullanılarak antimikrobiyel özellik kazandırılmış yanık yaralanmalarında kullanılan basınçlı giysiler tasarlamak ve geliştirmektir. Bunun için portatif bir manken ve ticari kablosuz basınç sensörleri kullanılarak basınç performansları çalışılmıştır. Altı farklı antimikrobiyel işlemin üç farklı tipte nylon6.6/spandex elastomerik kumaşların basınç davranışları birbirleriyle karşılaştırılmış ve değerlendirilmiştir. Ayrıca, antimikrobiyel işlem görmüş ve görmemiş nylon6.6/spandex elastomerik kumaşların basınç davranışları birbirleriyle karşılaştırılmış, incelenmiş ve değerlendirilmiştir.

Bunların yanında, altı farklı antimikrobiyel işlemin üç farklı tipte nylon6.6/spandex elastomerik kumaşın fiziksel ve mekanik özellikleri üzerindeki etkisi incelenmiştir. Farklı antimikrobiyel işlemler kullanılarak üç farklı nylon6.6/spandex elastomerik kumaşın fiziksel ve mekanik özellikleri birbirleriyle karşılaştırılmış ve değerlendirilmiştir. Altı farklı antimikrobiyel işlemin nylon6.6/spandex elastomerik kumaşlar üzerindeki komfor özellikleri de çalışılmıştır. Farklı antimikrobiyel işlemler kullanılarak üç tipte değişik nylon6.6/spandex elastomerik kumaşların komfor özellikleri birbirleriyle karşılaştırılmış ve komfor özellikleri üzerine etkisi değerlendirilmiştir.

Farklı antimikrobiyel mekanizmalar farklı alternatifler sunduğu için gümüş bazlı bileşenler, poliheksametilen biguanid (PHMB), quaternary amonyum bileşenleri (QAC's) ve Triclosan gibi çeşitli tipte antimikrobiyel teknolojiler çalışılmış ve çeşitli antimikrobiyel özellikli kimyasal maddeler kullanılarak çeşitli tipte kumaşlar geliştirilmiştir. Gümüş antimikrobiyellerin yüzeyleri üzerinde birçok bağlanma alanı bulundurması, yanık yaralanmalarının iyileştirilmesini hızlandırmaktayken, quaternary amonyum bileşenleri tekstil yapılarına kovalent bağlarla bağlandığından antimikrobiyel dayanımı en iyi performansı göstermiştir. Triclosan küçük bir molekül olduğundan, dispers boya gibi davranabilmekte ve çektirme yöntemiyle de kumaşlara aplike edilebilmektedir. Kimyasal olarak da kararlı bir yapıda olduğundan vücuttan da kolaylıkla uzaklaştırılabilmektedir. Fakat Triclosan Amerika Birleşik Devletleri Sağlık Bakanlığı (FDA) ve Kanada Sağlık Yasası (Canada Health) tarafından belirlenen bazı alerjik reaksiyonlara neden olabileceği ve Hijyen Hipotezi'ne göre vücudun bağışıklık sistemi üzerine olumsuz etkileri olabileceğinin belirlenmesi üzerine takip altındadır. Trıclosan, çok düşük konsantrasyonlarda antimikrobiyel özellik göstermektedir. Poliheksametilen biguanid (PHMB), kumaşlara dayanıklı antimikrobiyel özellik kazandırabilmesinin yanında kumaş sararmalarının da üstesinden gelecektir. Polimerde ortalama 16 biguanid birim içeren yüksek molekül ağırlığına sahip olduğundan tekstil yüzeylerine çok iyi bağlanabilmektedir.

Bu araştırmada yürütülen çalışmada, kablosuz basınç sensörleri kullanılarak basınçların kontrol edildiği çeşitli teknolojiler kullanılarak dayanıklı antimikrobiyel özelliğe sahip yanık yaralanmalarında kullanılan basınçlı giysi kullanımına yönelik yeni elastomerik kumaşlar geliştirilmesine odaklanılmıştır. Yanık yaralanmalarınınyönetiminde kullanılan yüksek elastanlı kumaşaların antimikrobiyel maddelerle optimum çalışma şartları için ana hatlar belirlenmiştir. Bu çalışma, yanık yaralanmalarında kullanılan basınçlı giysilere yönelik kumaşların klinik olarak basınç fonksiyonu ve rehabilitasyon performansları üzerine etkilerini belirlemek için değişik konsantrasyonlarda değişik antimikrobiyel bitim işlemleri uygulamalarıyla devam etmektedir.

Bu kumaşların rehabilitasyon hızına etkilerini incelemek için fare sırtı modeli kullanılarak hayvan deneylerinin de yürütülmesi istenmektedir. Bu aynı zamanda, yaşayan canlı mikroorganizmalar üzerinde alerjik reaksiyonların önlenmesi ile ilgili de bir fikir vereceği düşünülmektedir.

1. INTRODUCTION

Textile products particularly made from natural fibers have a serious problem of microorganism growth because of their surface area and ability to retain moisture. The use of antimicrobial agents for textiles has also become indispensible to avoid cross-infection by pathogenic microorganisms, to control the infestation by microbes, and arrest metabolism in microbes in order to reduce odor formation. Antimicrobial treated fabric protects garments from staining, discoloration, and quality deterioration [1-3].

The increasing demand for comfortable, aesthetic, durable, functional, and safe textile products dictates the development of new and contemporary techniques of processing and designing textiles. Therefore, it is becoming important day by day to include the superior functionality in daily wear which is durable and demanding. As far as antimicrobial property is concerned, numerous antimicrobial agents are known and have already been tested in combination with many hydrocarbon and fluorochemical and sol-gel based finishes have also been investigated by researchers and proved to have variable success [4-8].

The present study is based on improving the antimicrobial property of the burn pressure garments using various antimicrobial agents such as silver compounds, QAC-Silane, Triclosan and polyhexamethylene biguanide (PHMB) by mapping the rehabilitation technique of various types of burn pressure garments.

1.1 Research Goal and Study Objectives

The overall goal of this research is to develop novel elastomeric fabrics for burn pressure garments having durable antimicrobial property (up to 50 launderings) using various antimicrobial technologies.

Fundamental to the realization of this goal is the understanding of how various antimicrobial mechanisms affect the pressure behavior and the chemical, physical, mechanical and comfort properties of three different types of fabric structures. Therefore, five main objectives were identified and defined, as described below.

Objective 1. To study the effect of six different antimicrobial treatments on chemical properties of nylon 6.6/spandex fibers in different textile structures

- 1.1. To study the surface morphology by scanning electron microscopy (SEM) to determine and observe the changes on fibers of different textile structures.
- 1.2. To study changes in chemical structure of the fibers using Fourier transform infrared spectroscopy (FTIR).
- 1.3. To study surface chemistry by x-ray photoelectron spectroscopy (XPS) for antimicrobial treatments with different silver antimicrobial chemical agents.

Objective 2. To study the effect of six different types of antimicrobial agents on the durability of antimicrobial activity of different types of nylon 6.6/spandex fabrics

- 2.1. To study the effect of laundering cycles on antimicrobial activity to evaluate the relative durability of six different antimicrobial treatments.
- 2.2. To compare the effect of six different antimicrobial treatments and laundering cycles on three different treated and untreated nylon 6.6/spandex fabric structures.

Objective 3. To design and develop three different types of nylon 6.6/spandex fabrics for use in burn pressure garments with antimicrobial properties using six different types of antimicrobial treatments for pressure performance testing using a mannequin and commercial wireless pressure sensors to evaluate the change in pressure

- 3.1. To compare and evaluate the effect of six different types of antimicrobial treatment procedures on the pressure behavior of three different types of nylon 6.6/spandex elastomeric fabrics.

- 3.2. To study, compare and evaluate the pressure behavior of three types of treated and untreated nylon 6.6/spandex elastomeric fabrics.

Objective 4. To study the effect of six different antimicrobial treatments on the physical and mechanical properties of three different types of nylon 6.6/spandex elastomeric fabrics

- 4.1. To compare and evaluate changes in the physical and mechanical properties of three different nylon 6.6/spandex elastomeric fabrics following different antimicrobial treatments.

Objective 5. To study the effect of six different antimicrobial treatments on the comfort properties of nylon 6.6/spandex elastomeric fabrics

- 5.1. To compare and evaluate changes in the comfort properties of three different nylon 6.6/spandex elastomeric fabrics following different antimicrobial treatments.

2. REVIEW OF LITERATURE

Pressure garments are mainly used for managing third-degree burns that not only affect the outer and inner layers of the skin but also deeper tissues [9]. Pressure garments are used for the rehabilitation of hypertrophic scars by applying counter pressure to the affected area. When burn skin heals it can grow in an irregular scaring manner. Pressure garments help the skin to heal by pressing the healing skin down so that it grows in a flat manner [10-12].

The continuous wearing of pressure garments prevents the thickening, buckling, and nodular formations seen in hypertrophic scars. The external pressure applied by the garments decreases inflammatory response and the amount of blood in the scar, reducing itching and prevents collagen from synthesizing. In addition, pressure garments provide protection against injury. It should be noted that these garments must be worn for many weeks and months. It has been widely agreed that an ideal pressure garment should exert a pressure of 20mmHg on the underlying tissue, although the benchmark pressure has yet to be scientifically established [13-17]. The best approach can be an optimal medical range between (0mmHg – 50mmHg) according to the patients with lower to high lymphedema. Lower compression (4.82mmHg ± 2.99mmHg) are required for some patients with lower extremity lymphedema. Also low pressure levels are recommended for the garments used at the top of the body which range between (0mmHg – 20mmHg) due to being close to the heart.

Pressure garments normally contain elastic yarns and a great deal of research and development work has been carried out worldwide to characterize and develop novel pressure garments [18-22].

2.1 The Biological Inflammatory Response

Our skin is the largest organ that we have and it plays a crucial role is sustaining an equilibrium between our body's natural pressure, and the pressure that gravity puts

on our body. The natural external pressure that our skin applies to our body is hard to determine, but certain studies have claimed that pressures ranging from 10 to 30 mmHg maintained a constant blood flow within the forearm, leading us to believe that this is close to the natural pressure felt by skin to allow our blood pressure to remain normal. Trauma to the skin, such as burns, disrupts this normal pressure and can cause issues with the patient's vascular system because the correct amount of blood is not being transported to the injured area. Compression therapy has been widely used as a means to support and maintain normal blood flow throughout the injured area. Compression therapy is used for treating second degree deep burns, third degree burns, and fourth degree burns where the patient's normal skin is compromised and grafting must occur.

Second degree deep burns are characterized by complete destruction of the basal membrane, partial destruction of the dermis, and epidermal cell presence around hair follicles. Second degree deep burns show blistering however the underlying tissue does not blanche with pressure, and the wound usually heals within three to four weeks. If the burn does not heal naturally within that time, grafting is required. Third degree burns are characterized by complete destruction of the epidermis and dermis, with subcutaneous tissue mostly injured (Figure 2.1). These burns require grafting as they do not heal except for around the edges. Third degree burns are noticeable by brown, black, or white tissue that does not blister and has a loss of sensitivity due to nerve damage. The most severe burn type is fourth degree burns which affect the full skin underlying and tissues, including muscle, tendon, joint, and bone. These burns have a blackened appearance, and are dry and very painful. As with any injury that disrupts the skin, our body begins its natural defense and starts to repair the damaged tissue with "new" tissue, however this new tissue does not have the same physical and mechanical properties as the old tissue and in many cases grafting from another area of the patient's body is the best option to reduce scarring. Burn injuries cause a specific type of scar to form called hypertrophic scars, which are raised above the normal tissue level and are stiffer than the original skin. Compression therapy is believed to reduce the amount of hypertrophic scarring in burn victims, although there is not much research that supports the claim that increased pressure will reduce the scarring.

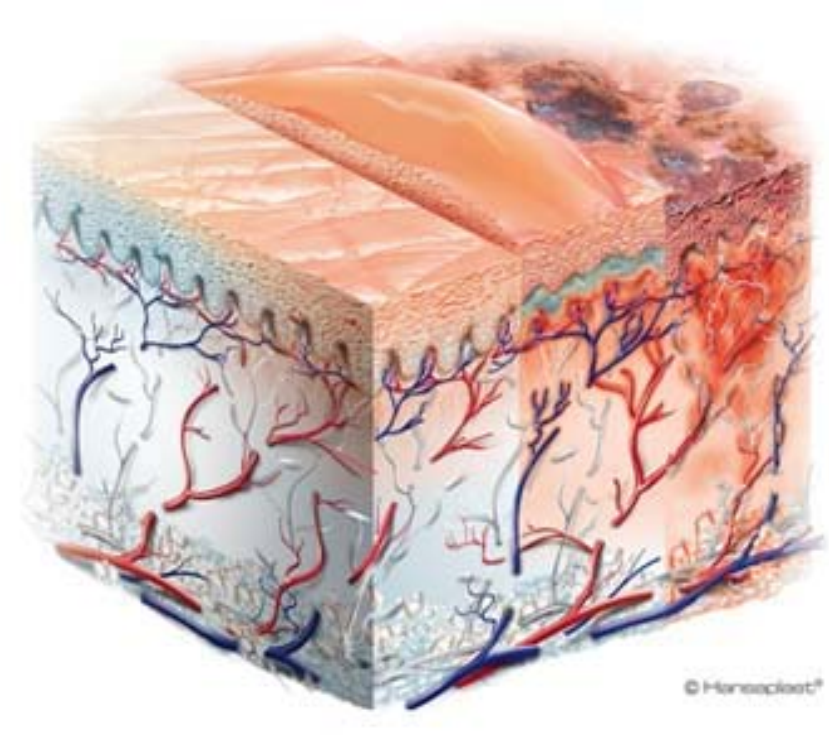


Figure 2.1: Damage of the inner, outer and deeper tissues by third-degree burn victims [18].

2.2 Wound Healing

Particularly in burn victims, the wound healing processes may lead to a fibrotic hypertrophic scar, which is raised, red, inflexible and responsible for serious functional and cosmetic problems. These scars are formed due an abnormal healing process where an overflow of collagen and fibronectin is present at the burn site (Figure 2.2). In comparison to normal wound healing, burns cause an increase of fibronectin to increase the fibroblast density and in turn increase the amount of collagen proteins. As fibroblasts enter the burn site they are converted to myofibroblasts and then into collagen, which is the connective tissue most present in the body. The over abundance of connective tissue causes the newly formed skin to be tighter and leads to mechanical tension on the wound, presenting functional problems for patients especially in facial and limb areas. In order to help burn victims regain their mobility compression therapy began in clinics in the late 1960's to try and reduce the thickness of the hypertrophic scarring and improve the scar's pliability. Although many pressure garment products exist in today's medical textile market, there are still problems that occur and a need for product improvement is present.

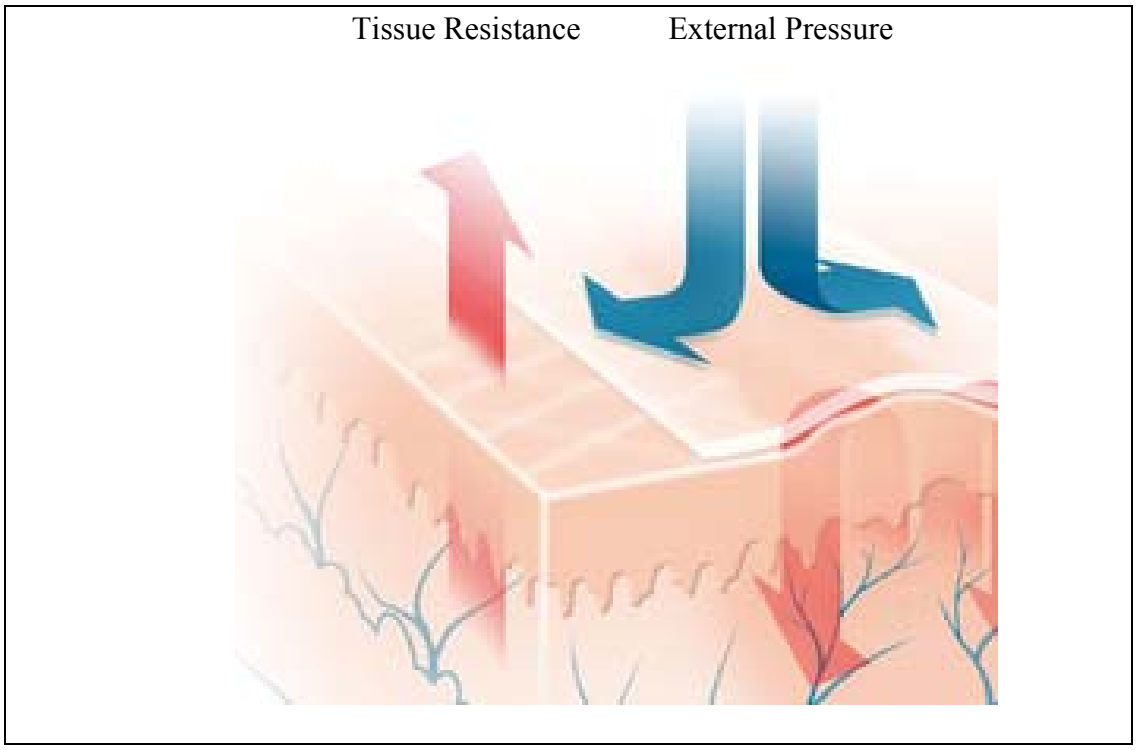


Figure 2.2: Burn scar management [23].

The care of burn patients has made steady progress. Until the first half of this century, even moderate burn injuries were usually fatal. The introduction of fluid resuscitation and the establishment of burn units have had a major impact on mortality [23-26].

Burn patients have subsequently benefited from many developments, including the introduction of systemic and topical antimicrobial agents, progress in intensive care and nutritional support, changes in surgical philosophy, advances in wound care and methods of achieving skin cover, and the concentration of treatment of patients with serious burns in specialist care. Alongside these improvements, the use of textiles in the patient's journey from injury to recovery has been crucial [27-29].

Obviously it is important to assess the depth and extent of the burn and commence fluid resuscitation, which involves catheterization, setting of intravenous fluids and possibly intubation for smoke inhalation [30-32]. Support surfaces, dressings, splinting, skin substitutes, pressure garments and silicone gels are needed to enable a burn patient to travel the road from injury to recovery [33-35]. Severe burns need to be treated on specialized beds. New matress coverings are water/moisture vapor permeable and have ability to transmit water vapor molecules through itself, while at

the same time remaining a complete barrier to liquids [36-38]. Hydrophilic materials have a good ability of absorption and transmit the moisture through the coating by a chemical mechanism [39-40]. Wound dressings are highly absorbent multilayered materials and protect the extensive burns efficiently [41-43]. Knitted bandages perform a number of functions including retention, support and cmpression and can give more support than traditional crepe woven bandages [44-47]. In extensive burns, there is a shortage of skin, and skin substitutes have to be considered in order to close the wound minimizing the risk of burn sepsis [48-49]. A permanent skin replacement is composed of a bilaminate membrane consisting of a bovine collagen based dermal analogue and a temporary epidermal substitute layer of silicone [50-52]. Split thickness skin grafts are used for the healing of large burns by accelarating the healing time of large areas of skin loss while protecting the underlying structures and reducing the risk of infection [53-54]. When the wound is almost healed and exudate levels are minimal, a semi-permeable polyurethane film is used which is impermeable to exudate and microorganisms and covered with a thin layer of adhesive [55-58].

2.3 Requirements for the Rehabilitation of Burn Scars with Burn Pressure Garments

Pressure garments were developed at the Shriners Burns Institute, Galveston, Texas. They have four main functions which are restoration of function, relief of symptoms, prevention of scar recurrence and promotion of optima aesthetic appearance. Pressure results in the reduction of the cohesiveness of the intercollagen fibres, increased vesicular fibroblasts and decreased mast cells. Most useful when the scar is still immature, and is used on burns that, have not healed within 14 days or have been grafted, and should be applied as soon as the wound has healed or has been surgically closed [59-61].

The materials used for the garments are either Lycra® or Elastane based. Lycra is a manmade premium stretch fabric which was invented and manufactured by Du Pont, it is a continuous filament elastic yarn, which can be combined with other yarns such as cotton or nylon. Elastane (Spandex), is a manufactured fibre in which the fibre forming substance is a long chain synthetic polymer comprising of at least 85% of a segmented polyurethane. Initially patients may start with low pressured garments and

progress to high pressured garments as the graft becomes more stable. The manufacturers also use suede and leather to make garments more durable, and hydrophobic fabrics, which are elastic and have a wick-like action and which are softer and more comfortable to wear.

Effective pressure is sometimes impossible to achieve in scars located in anatomical depressions, over flexures or during movement. Also patients may not tolerate pressure therapy. A useful adjunct is silicone gel, it can be used prophylactively or as a sole treatment or in conjunction with pressure therapy. The mechanism of action is not really understood, pressure, temperature and oxygen tension have all been investigated, but the most common theory is that softening and flattening of the scar occurs due to hydration of the scar. Silicon is the second abundant element in the earth's crust, comprising about 20%. It is formed in sand, minerals, and rocks. Silicone is a manmade material; the raw materials include silicon, water and oil [68-73]. Silicone gels are comfortable, durable, and easy to apply and remove, non-antigenic and non-toxic. They are known for softening and reducing scars. They can be removed for bathing and can be washed in warm water and reapplied. Patients are advised to build up wear time until patients can tolerate 8 hours or more, and ensure good hygiene of the product. Many gels now exist and can be used for different areas of the body, and are available on authorising (FP10) prescription which is the legal authority to supply the medication. Cica-care is a cured silicone gel laminated to an elastomeric silicone membrane. Mepiform is made of thin, pliable polyurethane, viscous, nonwoven backing covered with a soft silicone Safetac layer, and a polyolefin release film protects the Safetac layer. Silgel, is a high molecular weight silicone gel made of polysilaxone and Novagel, a product based on glycerin, can be used when silicone reactions occur. The gels are self-adhesive or can be held in place by bandages, tape, silicone adhesive or pressure garments [74-79].

2.4 Exerted Pressures for the Healing Process

There are many important properties that pressure garments must possess, most of which are mechanical due to the fact that the device is external. The most vital aspect of the pressure garment is the tension (in Nm^{-1}) because it directly influences the amount of pressure that is exerted onto the patient. The type of fiber used and the fabric construction method play a critical role in the amount of pressure that is

exerted as well as the fit of the garment. The garment must be made smaller than the body that it will be on to ensure pressure is exerted. The pressure garments are divided into two classes to identify compression strengths as “low” and “high” compression class according to hypertrophic scar characterization. The color and rigidity of the hypertrophic scars may vary among the patients. The required pressures show differences among race, ethnicity, skin color, age, scar thickness, location of injury and time of wound healing. Some patients may require garments of lower compression (0–15mmHg), some patients may require high pressure garments (24mmHg pressure or above). The pressure must be maintained for a minimum of 12 months, during which time the garments should be worn 23 hours per day. Although mechanism of action is not validated, over 24mmHg is a level that exceeds the inherent capillary pressure and therefore ensures occlusion. Tailor made pressure garments are used to apply pressure and must be changed regularly. They are available commercially from Kendall Camp, Gilbert & Mellish, Second Skin or Jobskin.

The required pressures show a variety according to the skin, age, and scar thickness and rehabilitation responses of the patients. These kinds of stockings exert an external pressure on limbs, which lead to the reduction of the vein diameter and increased blood flow. The compression stockings should be able to preserve their compressive pressure even after being worn for an entire day and not lose their elastic stretch recovery. However, fabrics show viscoelastic properties and their recovery depends on the drawn ratio. So the exerted loads in the production process and during application of fabrics causes stretch and deformations in the fabric. At the beginning of drawing a fabric, the deformation is completely recoverable, but increasing the load on the fabric leads to movement of fibers in the yarn core, this causes time-dependent deformation. The time-dependent deformation is also recoverable, which recovers with time and depends on the initial load. The degree of deformation depends on the several factors such as chemical composition, construction, mass, and thickness of the fabric. Since in the production process and during application the lower loads are exerted, resulting deformations are not permanent. It means that the initial deformation of the fabric after loading consists of two elements, the recoverable deformation (elastic deformation) and deformations which are recoverable in time (primary creep). Thus if a fabric is under tension over

a long period of time, some of the stresses in it will be relieved, with a consequent reduction in the skin-and-garment interfacial pressure. This is the fabric problem of having a viscoelastic response to an applied load and is very important, especially in medical pressure garments such as compression stockings. For clinical treatments, it is critical to maintain the pressure on the scar area, within a certain range according to instructions from doctors or therapists. The decline of pressure in the elastic fabrics affects the clinical efficiency of pressure garments.

Another important consideration with pressure garments is the amount of time that they will adequately exert pressure onto the body. This varies depending on the material used and the care the garment receives; garments can last as short as 3 weeks or as long as 3 months. The ointments and lotions that are applied to the skin beneath the pressure garments also play a large role in determining how long they will retain their strength and elasticity; water based creams do not break the pressure garment down as fast. Additionally people with the following conditions must first consult a doctor before using the product: neuropathy, paralysis, diabetes with small vessel damage, and those who have arterial insufficiency.

2.5 Comfort Requirements from Burn Pressure Garments

Pressure garments should be worn 24 hours a day during rehabilitation stage in order to provide improvement on the burn scar tissues. So they must be comfortable to the patients by removing excess heat from the body and circulate air through the body. By providing needed comfort with enough moisture, the rehabilitaiton rates will be increased and the wounds will be prevented that are supposed to be caused by the wet environment for the burn scar areas. Thus leading an ideal rehabilitation stage for the patients and also the excess costs will be prevented.

2.6 Antimicrobial Treatments of Textiles

Antimicrobial textiles are classified as those textile and fibrous materials subjected to various finishing techniques to afford protection for both the user of textile materials (against bacteria, yeast, dermatophytic fungi and other related microorganisms for aesthetic, hygienic or medical purposes) [80] and the textile itself (biodeterioration caused by mould, mildew and rot producing fungi) without negatively affecting the other important characteristics of the textiles [81-86].

With a view to develop antimicrobial textile materials, considerable research has been carried out by making use of organic and inorganic compounds, antibiotics, heterocyclics, quaternary ammonium compounds and so on [87,88]. Several studies have been carried out ranging from fundamental aspects to development of antimicrobial fabrics. Antibacterial polyester fabrics have been developed by imbuing antibacterial agents into the structure of fibers rather than depositing on their surface for longer durability and effect. It is stated that the efficacy of the finished fabric to arrest the growth of *Staphylococcus aureus* and *Escherichia coli* is about 5 times higher than the conventional materials. A synergistic system of formulation comprising of inorganic chemicals involving a metal salt of a monocarboxylic acid, a carbonic acid derivative, a chelating agent, a boron compound, a dimethylene siloxane derivative and an alkane polymer has been proved to serve as an effective antimicrobial agent in arresting the growth of several bacteria, fungi and mildew. Hospital trials showed a dramatic decrease in bacteria, fungi and mildew growth in treated fabrics. The treatment also prevents the deterioration of fabrics by microorganisms [89]. Chitosan treatment on cotton renders antimicrobial activity. Chitosan treated cotton fabric showed a high reduction rate in the number of colonies [90]. Fabrics made from viscose fibers containing polysilicic acid (Visil) and aluminum silicate (Visil AP) have been given urea peroxide treatment to make them antibacterial as well as deodorizing. Instead of treating the surface of the fabrics with polymer coating, antibacterial additives have been imbedded into the fabric's polymer fibers for the production of antibacterial gowns [91-95].

The ideal biocidal textile materials for medical use should possess the following features:

- Rapid inactivation of a broad spectrum of microorganisms [96-98]
- Non-selective and non-immutable to pathogens
- Non-toxic and environmentally friendly
- Durable to repeated washes
- Easy to recharge in laundering or disinfection processes [99-102]

In addition, the recharging agents should be non-toxic, available at home, and compatible with our laundering chemicals such as detergents or bleaching agents [103-105].

2.6.1 Antimicrobial chemical agents

The number of healthcare equipment manufacturers incorporating antimicrobial properties in their products has increased dramatically in recent years. Various types of antimicrobial chemical agents are used to impart antimicrobial properties to textiles. They have different properties and mechanisms [106-108].

2.6.1.1 Triclosan

Triclosan is an antibacterial and antifungal agent. It is a polychloro phenoxy phenol. It's been used since 1972 and it is present in soaps (0.10-1.00%), deodorants, toothpastes, shaving creams, mouth washes, and cleaning supplies, and is infused in an increasing number of consumer products, such as kitchen utensils, toys, bedding, socks, and trash bags [109-110]. Triclosan has been shown to be effective in reducing and controlling bacterial contamination on the hands and on treated products. More recently, showering or bathing with 2% Triclosan has become a recommended regimen for the decolonization of patients whose skin is carrying methicillin-resistant Staphylococcus aureus.

This organic compound is a white powdered solid with a slight aromatic/phenolic odor. It is a chlorinated aromatic compound that has functional groups representative of both ethers and phenols. Phenols often show antibacterial properties.

Triclosan (2,4,4'-trichloro-2'-hydroxydiphenylether) is a broad-spectrum antimicrobial agent with a MIC of less than 10ppm against many common bacterial species (Figure 2.3).

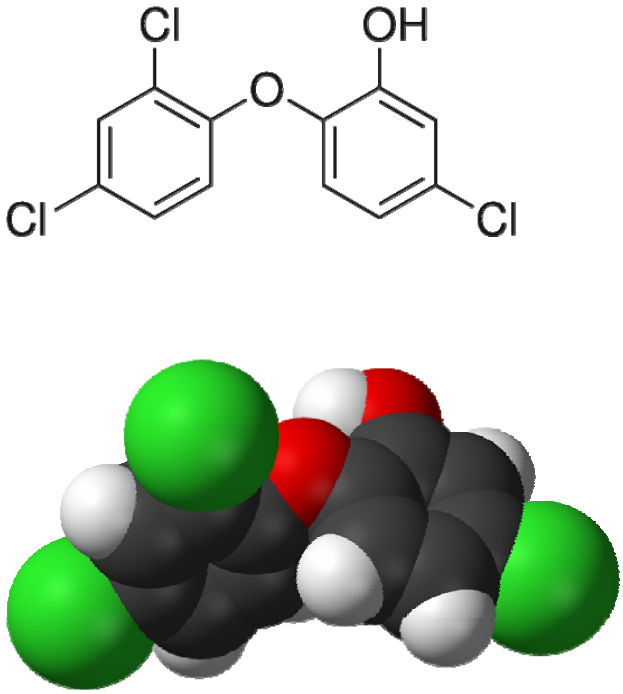


Figure 2.3: Structure of Triclosan [113].

Triclosan antimicrobial mechanism

At in-use concentrations, Triclosan acts as a biocide, with multiple cytoplasmic and membrane targets. At lower concentrations, however, Triclosan appears bacteriostatic and is seen to target bacteria mainly by inhibiting fatty acid synthesis (Figure 2.4). Triclosan binds to bacterial enoyl-acyl carrier protein reductase enzyme (ENR), which is encoded by the gene FabI. This binding increases the enzyme's affinity for nicotinamide adenine dinucleotide (NAD^+) [111].

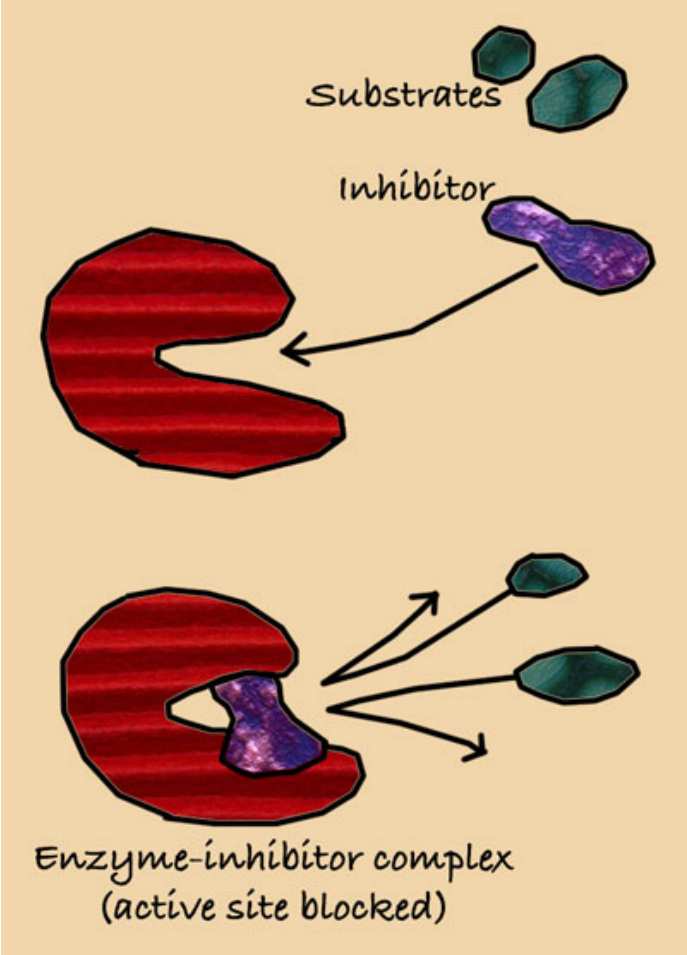


Figure 2.4: Triclosan antimicrobial mechanism [113].

Being a relatively small molecule, Triclosan can also act like a disperse dye and can be used by exhaustion prior to dyeing, together with dyeing or after dyeing of polyester and nylon fibers at 5% owf. During the fabric use, the agent migrates to the surface of the treated textiles at a slow yet sustained rate to provide antimicrobial efficacy [112-115].

2.6.1.2 Silver

Technology now allows silver ions to be incorporated into a diverse range of materials including fabrics, plastics and paints. The range of silver-based antimicrobial products is extensive and set to expand. Demonstration of silver ion efficacy against medically important bacteria is important but well-recognized [116]. The widespread use of silver-treated products in the healthcare environment would be supported by data showing its effectiveness against bacteria in that environment because a case could be presented that significant reduction of contaminants in

patient-containing environments infers potential for reducing Healthcare Associated Infections (HCAIs) [117,118].

Silver is the oldest and most efficient of the antibiotics known; it's also the safest. In the past 40 years, silver has been incorporated into, coated on a wide range of natural or synthetic materials for wound care and other medical devices. Silver-coated textiles have a special value in reducing risk of pathogenic infection such as Staphylococcus aureus in patients with atopic eczema [119-122].

Silver ions antimicrobial mechanism

The silver kills microbes by interacting with multiple binding sites on their surfaces (Figure 2.5). Silver is also proposed to act by binding to key functional groups of enzymes by causing the release of K+ ions from bacteria [123,124]. This is an important target site for silver ions to kill the bacteria. Silver ions also inhibit bacterial growth by inhibiting cell division and damaging the cells of bacteria [125,126].

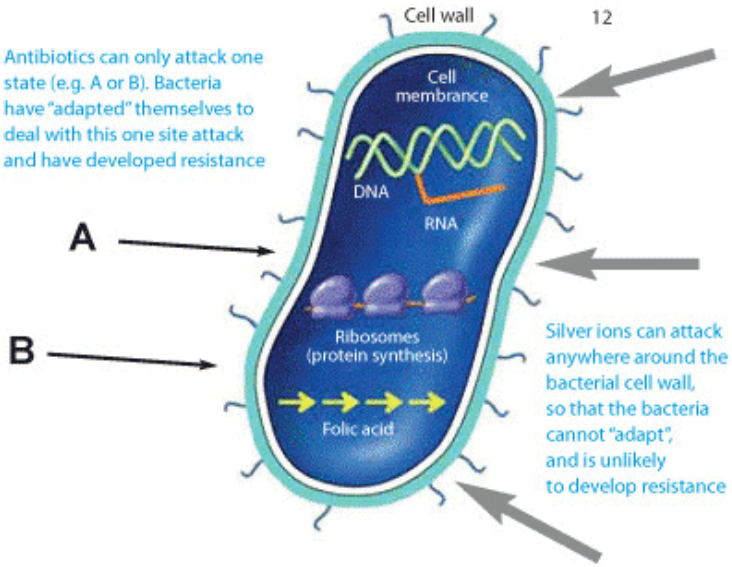


Figure 2.5: Silver ions antimicrobial mechanism [126].

Numerous patent applications have been filed recently claiming new technology for "silvering" textile fibers with activity against antibacterial or antifungal infections [127]. In each case, the textile fibers serve as a vehicle for delivery of bioactive silver ion (with or without promotion by a direct electric current) to eliminate or otherwise protect against bacterial imbalances in the skin, microbial over growth accompanied by excessive odor or local discomfort [128-130].

Techniques for silver coating or impregnation of textile fibers will achieve a sustained rate of silver ion release; the treatment will result in a homogeneous distribution of silver over the surface of the fiber or through the interstices of individual threads. The silver-fiber binding should be stable and provide long-standing ionic release sufficient to withstand everyday wear-and tear, exposure to ultraviolet (UV) light and other environmental factors [131-134].

2.6.1.3 Quaternary ammonium compounds (QAC)

Quaternary ammonium cations, also known as quats, are positively charged polyatomic ions of the structure NR4+, R being an alkyl group or an aryl group (Figure 2.6) [135,136].

Quats have antimicrobial effect against;

- Vegetative bacteria,
- yeast,
- molds,
- algae,
- viruses [137-141]

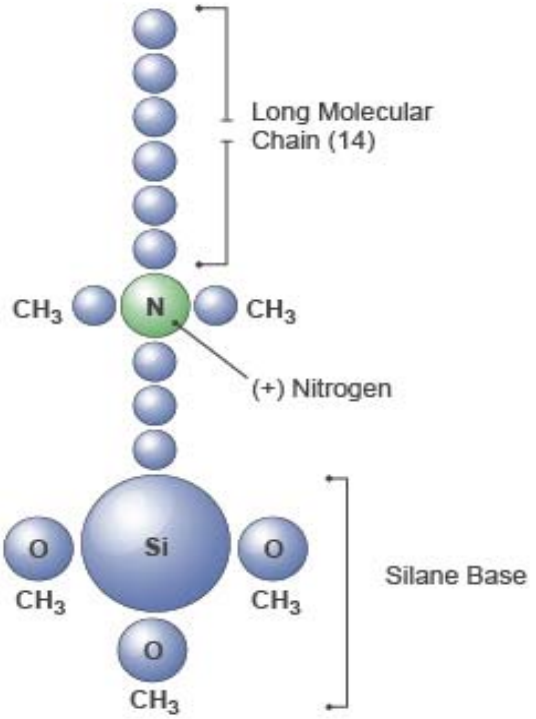


Figure 2.6: Chemical Structure of QAC [142].

QAC antimicrobial mechanism

QACs have antimicrobial effect against a broad range of microorganisms including vegetative bacteria, yeast, molds, algae, and viruses. QACs can inhibit germination of bacterial spores and the growth of vegetative bacteria,yeast,molds,and algae [143-145]. The growth inhibitory activity of QACs is higher for gram-positive bacteria and algae compared with gram-negative bacteria and molds. Quats are positively charged polyatomic ions of the structure. It disrupts the virus, bacteria etc, by use of chemicals [146-148].

Silanes are extremely efficient bonding agents that can be coupled to other molecules and then used to permanently bond those molecules to a target surface (Figure 2.7) [149-152].

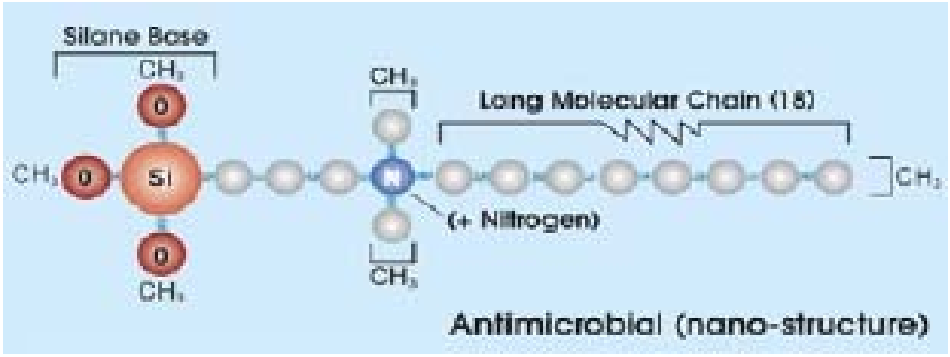


Figure 2.7: Quat-Silanes working mechanism [152].

2.6.1.4 Polyhexamethylene biguanide (PHMB)

Polyhexamethylene biguanide (PHMB) also known as polyhexanide and polyaminopropyl biguanide is a commonly used antiseptic (Figure 2.8) [153]. Polyhexamethylene biguanide is a potent biocide with broad spectral activity against both gram positive and negative bacteria, yet with low toxicity to higher organisms [154-157]. The minimal inhibitory concentrations range from 0.5 (e.g., against Staphylococcus aureus) to 10 ppm (e.g.,against Klebsiella pneumoniae). It has long been used as a disinfectant in the food industry, sanitization of swimming pools and more recently applied to cotton to produce antimicrobial textiles. Polyguanidine oligomers, particularly polyhexamethylene biguanide (PHMB) oligomer are used extensively and safely as disinfectants and biocides [158-162].

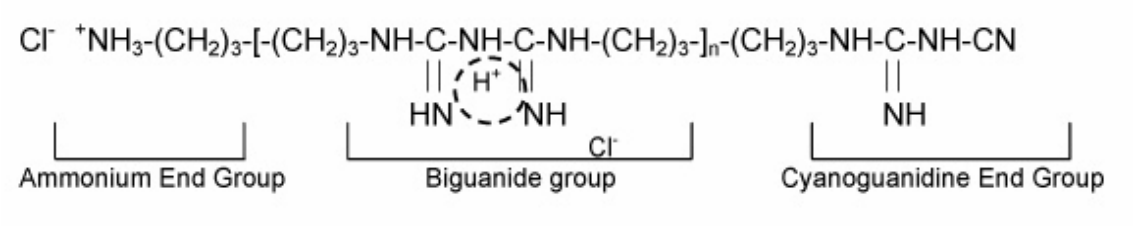
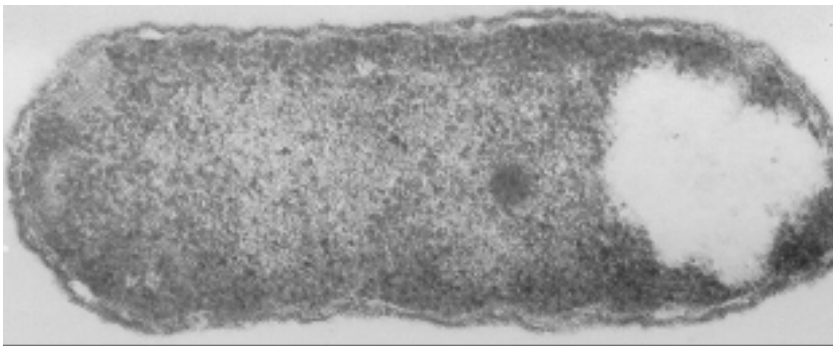


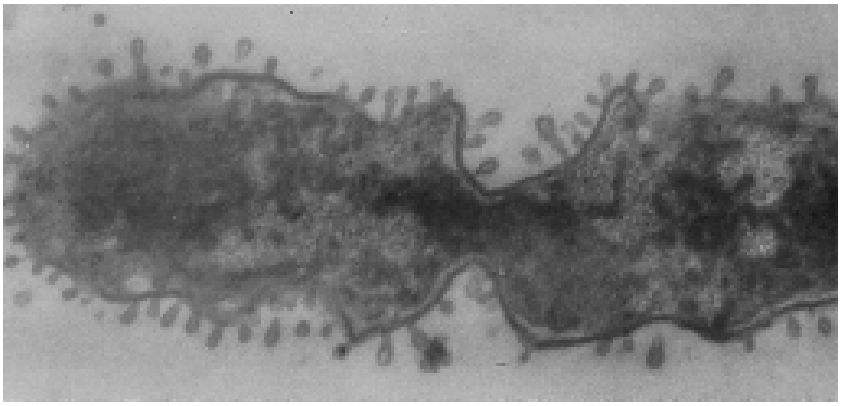
Figure 2.8: General formula of PHMB [161].

PHMB antimicrobial mechanism

PHMB is a strong, fast acting and broad spectral biocide against bacteria. The antibacterial activity of PHMB is attributed to its interaction with cellar membrane components. It kills bacteria by puncturing their cell membranes, causing the contents to leak out (Figure 2.9). It does not have the same effect on human cells so it is safe to use in contact with skin.



A bacterium before treatment with PHMB
(Picture courtesy of Arch Biocides UK Ltd)



A bacterium after treatment with PHMB
(Picture courtesy of Arch Biocides UK Ltd)

Figure 2.9: PHMB antimicrobial mechanism [164].

PHMB has a higher activity against planktonic bacteria in studying biofilms. They are also the most effective agents against sessile bacteria found within biofilms. The effect of concentration of PHMB on planktonic versus sessile bacteria is due to either the mechanism of action or the number or disposition of cationic binding sites. Also PHMB promotes contraction and aided wound closure significantly [163-165].

The mechanism of action of PHMB has been described in a number of articles. Maximal activity of the PHMB occurs at between pH 5-6 and that initially the biocide interacts with the surface of the bacteria and then is transferred to the cytoplasm and cytoplasmic membrane. The cationic PHMB has little effect on neutral phospholipids in the bacterial membrane. Its effect is mainly on the acidic negatively charged species where it induced aggregation leading to increased fluidity and permeability. This results in the release of lipopolysaccharides from the outer membrane, potassium ion efflux, and eventual organism death [166,167].

Biguanide groups are the active part of the PHMB. Compared to other biguanides, the fact that biguanide groups are separated by a C6 aliphatic hydrocarbonated chain gives to PHMB a particularly high efficacy power on a wide range of microorganisms.

A simple description of the mechanism of action of PHMB against bacteria is as follows:

1.PHMB is quickly attracted to the bacteria surface

2.PHMB neutralizes the cell wall protection system (called « exclusion system»): it combines with proteins in charge of this defense

3. PHMB passes through the cell wall to join the cytoplasmic membrane

4. PHMB enters in the 1st stage of its action against bacteria (bacteriostatic level: reversible): PHMB creates some spaces in the cytoplasmic membrane by association with proteins. This starts up the loss of little size compounds (potassium, calcium…): membrane is getting permeable

5. PHMB enter in the 2nd stage of its action against bacteria (bactericidal level: not reversible): PHMB breaks up the cell cytoplasmic membrane. The cell looses its vital compounds

6. The cell dies

2.6.2 Use of treatment techniques to impart antimicrobial properties

There are a number of techiques for the applications of antimicrobial treatments to textiles. For example; coatings based on inorganic-organic hybrid polymers, derived by the sol-gel process have an immense potential for creative modifications of surface properties with an comparatively low technical effort and at moderate temperatures. The coatings often combine properties of organic polymers with those of ceramic materials. Therefore those hybrid polymers are of an enormous interest for textile coatings mainly for technical textiles. These basic materials offer the opportunity to produce very hard but flexible coatings, especially by filling or modifying the networks with nano-particles. Approaches to modify such coatings by various inorganic or organic substances achieve a huge number of additional functionalities, asked in textile industries. Coatings of a thickness of less then one micron can act as effective barriers against chemical attacks, super-repellent surfaces can be created, the wear-resistance of textile materials can be improved. Certain coatings protect sensitive polymers against decomposition due to ultraviolet radiation using nanoparticles as employed in sun creams. Ballistic body wear based on fabrics protect against guns but it does not properly protect against knives, thin coatings based on inorganic-organic hybrid polymer filled with alumina nanoparticles achieved good stab-resistance for such products. Further approaches deal e.g. with reversible photochromic coatings – coatings that change its colour if irradiated with sun light, magnetic hybrid polymers or medical systems based on porous sol-gel-coatings with immobilized drugs that are released in contact with skin [168-172].

Increasing demands for functional and highly specialized textiles, e.g. technical textiles can be observed worldwide. Intense research presently aims at new methods for surface modification in order to establish improved or new properties. An innovative method for textile finishing is the modification of fibre material with a thin coating of organically modified ceramics or inorganic-organic hybrid polymers that combine the advantages of organic polymers and ceramics.

In the sol-gel technique, organically modified ceramics, which are made by sol-gel-processing, combine qualities of ceramics and synthetic polymers and have an immense potential for creative modifications of surface properties with a low technical effort at moderate temperatures. These materials are derived from silica-alkoxides that are modified with one organic group. This group consists of e.g. a

hydrocarbon chain with functional epoxy-, metacrylic or thiol-groups. In the presence of certain amounts of water, under basic or acidic conditions these alkoxides undergo a hydrolysis reaction and partly condense to form sols. In a following curing step the condensation of the hydrolyzed silica-alkoxides can be completed by simultaneously cross-linking of the functional groups. Mixing with other metal alkoxides or dispersing nanosized metal-oxides can modify the sols. Therefore the resulting three-dimensional networks are built from organic and inorganic domains. The sols can be applied by common methods as e.g. dipping, spraying or knife coating and in contrast to ceramic processing the curing temperatures are very moderate. Depending on the organic modification the curing can be carried out with UV-radiation as well. A low temperature and cost-effective process for antimicrobial finishing of cotton textiles has been developed by sol-gel method. The antimicrobial treatment was performed by treating cotton textile with silica sols from water glass and then with silver nitrate solution. The antimicrobial activity was determined by using E. coli as a model for Gram-negative bacteria. The results showed that the treated textile has an excellent antimicrobial effect and laundering durability. SEM analysis showed coarse surface morphological change on the water glass treated cotton textile. The residual concentration of silver ion on fabrics was informed by ICP-MS. XPS results indicated that two different states of silver were present on the surface of the antimicrobial textile. Medical implants and indwelling medical devices can be painful and pose risk of infection or rejection. Antimicrobial coatings help alleviate the risk and potential costs of device replacement. Microbial growth in uncoated sample and sample coated with PVA as a carrier (14 days) can be seen in Figure 2.10 [173-178].

Figure 2.10: Microbial growth in uncoated sample and sample coated with PVA as a carrier (14 Days) [175].

Advantages of Antimicrobial Coatings

- Duration of release can be tailored from hours to several months.
- Biocompatible according to coating properties.
- Thin to thick coatings can be applied to textiles according to the medical device function.
- Tolerates sterilization even GAMA.
- Different properties can be added to textiles according to coating properties as analgesic, anti-inflammatory, anti-thrombotic and other suitable drugs can be used for medical applications.

Another technique is plasma treatment to impart antimicrobial properties to textiles. As a dry and eco-friendly technology, plasma technique is offering an attractive alternative to add new functionalities such as water repellency, long-term hydrophilicity, mechanical, electrical and antibacterial properties as well as biocompatibility due to the nano-scaled modification on textiles and fibers. At the same time, the bulk properties as well as the touch of the textiles remain unaffected. Products made with the help of textiles and fibers become more and more sophisticated and "multifunctional". Tailored surface modifications are required to meet customer needs and to assure a share in the market. However, conventional finishing techniques applied to textiles (dyeing, stain repellence, flame retardance, antibacterial treatments) generally use wet-chemical process steps and produce a lot of wastewater.

Plasma, often referred to as the fourth state of matter, is an ionized gas consisting of highly energetic electrons and positive ions. Plasmas are generated by high electric fields and can interact with solids to provide unique surface properties. Plasma treatments have been used to induce both surface modifications and bulk property enhancements of textile materials, resulting in improvements to textile products ranging from conventional fabrics to advanced composites. These treatments have been shown to enhance dyeing rates of polymers, to improve colorfastness and wash resistance of fabrics, to increase adhesion of coatings, and to modify the wettability of fibers and fabrics. Research has shown that improvements in toughness, tenacity, and shrink resistance can be achieved by subjecting various thermoplastic fibers to a plasma atmosphere. Recently, plasma treatments have produced increased moisture

absorption in fibers, altered degradation rates of biomedical materials (such as sutures), and deposition of low friction coatings.

Plasma treatment may be performed either at low pressures (vacuum) or at atmospheric pressures. Although vacuum plasma processes are well understood and are used extensively in the semiconductor industry, the fact that vacuum conditions are necessary makes low pressure plasma impractical to use in industries requiring high rates of throughput, e.g., the textile industry. Atmospheric plasma treatment, on the other hand, is well suited for continuous processing, but the technology is relatively new, and not completely understood.

Plasma treatments are carried out in a plasma equipment where the samples are treated with antimicrobial, hydrophobic, or other surface treatments. Plasma treatment results in surface reactions, e.g. etching and deposition of the reaction products of the plasma. There are many interactions which take place during plasma processing between the reactive plasma and fabric surfaces. Bulk properties of plasma treated textile materials remains almost unaffected by low pressure plasma treatments. A laboratory plasma device is capable of exposing textile materials to atmospheric plasma conditions in a continuous process. Altough atmospheric plasma treatment has the capability to enhance or replace conventional wet finishing processes as well as produce novel fiber surfaces, the process and the obtained results from the process are still not maintained [179-182].

The wet finishing treatment to increase antimicrobial and other effect of the fabric is carried out under the application of finishing agents like antimicrobial agents, by means of a well-known padding method. The wet finishing treatment can be seen in Figure 2.11. After a short immersion (2 min.) in a bath of finishing chemicals the fabric is then padded with 60 – 70% pick-up, afterwards is dried (100°C / 2 min.) and condensed (160°C / 2 min.) to attain the maximum effectiveness of the treatments.

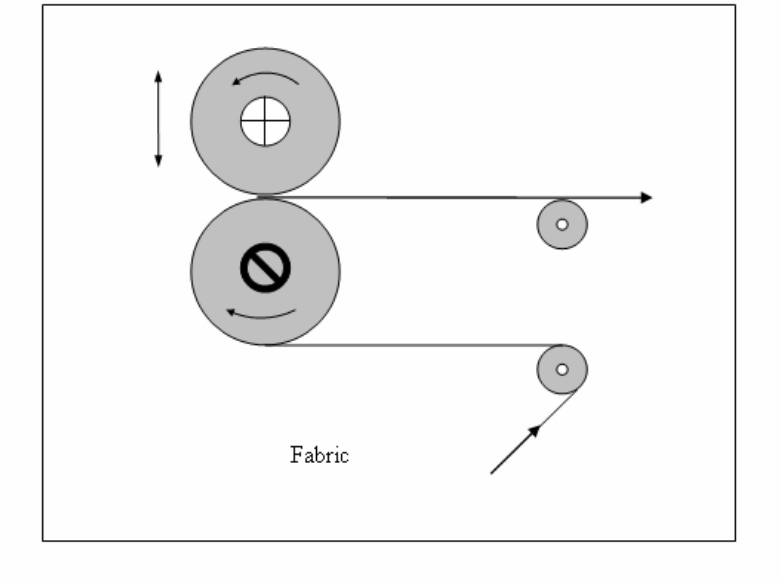


Figure 2.11: Padding mangle [180].

Depending entirely on the specific chemicals applied wet finishing chemicals make the fabric hydrophobic leaving a thin polymer film on its surface. As finishing chemicals, acrylate based fluorocarbon and polymethyl hydrogen siloxane as well as a non-ionic detergent with different concentrations and many other chemicals are used according to the required property, like antimicrobial effect, hydrophobic, air permeable, etc.

Immersion or soaking in a bath is a simple and quick technology. Antimicrobial chemical agents can be applied to fabrics simply and quickly by immersion or soaking in a bath, by vaporization, or by adding to a wash after the rinse cycle. The colorfastness and feel of textiles are good.

Exhaustion techniques are discontinuous processes with a long time for the reaction of the chemicals with textile materials. In an exhaustion principle, a certain amount of textile material is loaded into the machine and brought to the equilibrium with a solution containing the chemicals, such as dyes and textile auxiliaries over a period of minutes to hours. Exhaustion process involves the desorption and absorption of dyes and textile auxiliaries from dyebaths (or any liquors) due to the substantivity of the chemicals to the textile substrate. Textile wet finishing processes, especially exhaustion methods, have higher rates of energy consumption due to both higher fluid temperatures and volume [183, 184].

3. RESEARCH DESIGN AND METHODOLOGY

3.1 Materials

Three fabric structures were selected and used in this work.

- 240,8 g/m^2 70/30 Nylon 6.6/Spandex in powernet warp knitted structure,
- 163,9 g/m^2 70/30 Nylon 6.6/Spandex in flat warp knitted structure and
- 275,6 g/m^2 75/25 Nylon 6.6/Spandex in weft knitted structure fabrics were used.

Grey elastane fabric in powernet warp knitted structure was supplied from BSN Medical Inc.(Jobst), flat warp knitted grey elastane fabric was supplied from Raineywear Essentials,Inc. and weft knitted grey elastane fabric was supplied from Medi Manufacturing Inc.

Three fabrics were selected in this work to see the effect of different textile structures on:

- the chemical properties
- the antimicrobial activity
- the behavior with different types of antimicrobial mechanisms
- the physical, mechanical, and thermophysiological comfort properties
- the pressure behavior

The fabrics are in powernet warp knitting, locknit warp knitting and 1x1 rib weft knitting structures. Insertion warp knits include both tricot and raschel knits. Extra yarns may be inserted in the warp or the filling direction of warp knits. If they are inserted in the warp direction, they are called inlay yarns. A powernet fabric is a raschel knit with inlaid spandex yarns (Figure 3.1). The spandex provides additional stretch and comfort to the garments.

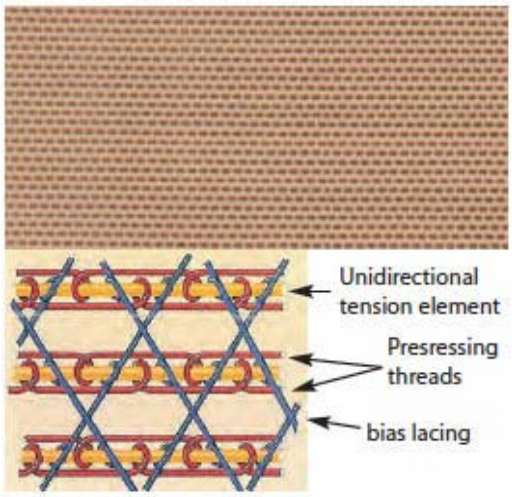


Figure 3.1: Powernet fabric structure.

In warp knitting forms fabric by interlacing loops of yarn, but vertically down the length of the fabric in contrast to weft knitting. Each needle in the knitting width must be fed by at least one yarn and in line with the direction of fabric production. It is the fastest method of fabric production using mainly continuous filament yarns. Locknit is the most popular two-bar structure. The longer underlaps of the front guide bar plate on the technical back of the fabric and the lapping movements are shown in Figure 3.2 which improves fabric extensibility, cover and handle, so that the structure is ideal for use as an apparel fabric.

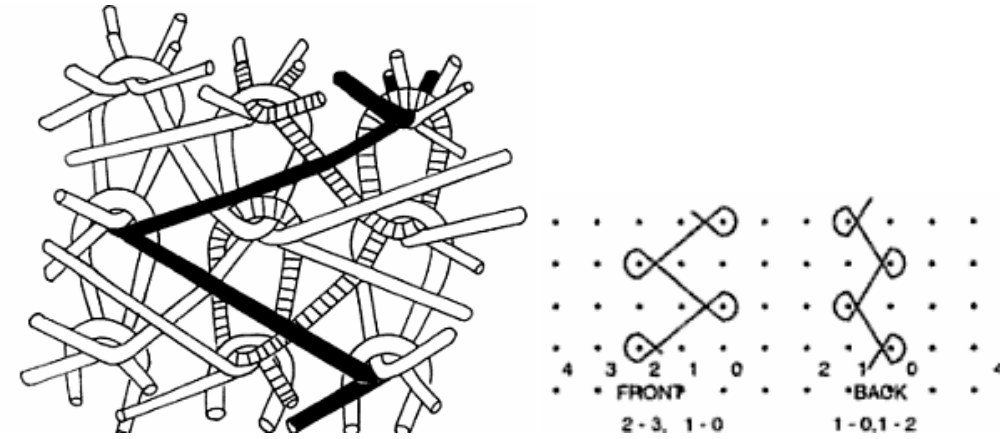


Figure 3.2: Locknit two-guide bar warp knit structure.

Spandex yarns are inserted into the structure in machine direction laying in the wale line adding extra elasticity to these units. Super stretch knits stretch 100 percent or more in both directions (two-way stretch nylon/spandex).

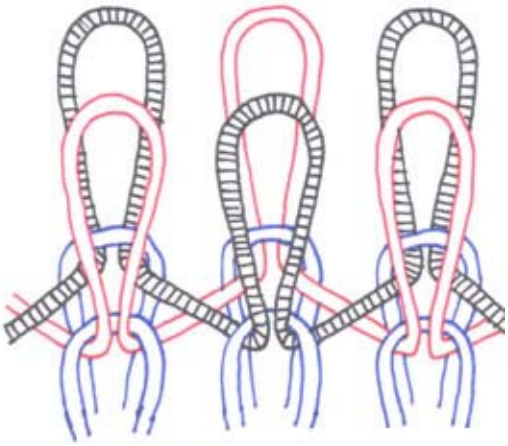


Figure 3.3: 1 X 1 rib double-jersey fabric.

The third selected fabric is a 1 X 1 rib double-jersey fabric as shown in Figure 3.3. The loops are formed across the width of the fabric in weft knittings giving a high stretch in widthwise. The width occupied by a 1 X 1 rib fabric is about half width of a plain fabric produced on the same number of needles, but it does have nearly twice as much as elasticity in the width. Lengthwise, the elasticity varies from moderate to high, depending upon the yarn used. Elastanes are always processed with one or more other fibers and never individually. Fabric specifications were listed in Table 3.1. The fabric contains 25% or more Spandex. The thickness varies from 102 to 313 g/m^2 and the area density varies from 164 to 277 g/m^2 0.5mm and the area density varies from 102 to 313g/m^2.

Table 3.1: Fabric specifications.

Fabric Type	Properties	Value
Powernet warp knitted	Nylon/Spandex	70/30
	Thickness (mm)	0.50
	Area density (g/m^2)	241
Flat warp knitted	Nylon/Spandex	70/30
	Thickness (mm)	0.57
	Area density (g/m^2)	164
Weft knitted	Nylon/Spandex	75/25
	Thickness (mm)	0.62
	Area density (g/m^2)	277

Table 3.2 lists some commercial elastomeric fabrics for a comparison. It can be seen that the fabric contains 25% or more Spandex. The thickness is around 0.5mm and the area density varies from 102 to 313g/m^2. The commercial fabric structures can be

in the texture of weft and warp knittings such as single-jersey, 1x1 Rib, Locknit,etc. They have many uses according to burn scar areas as head, neck, foot as shown in Table 3.3.

Table 3.2: Some commercial elastomeric fabrics.

Fabric Type	Properties	Value
A	Nylon/Spandex	75/25
	Thickness (mm)	0.48
	Area density (g/m^2)	102
B	Nylon/Spandex	72/28
	Thickness (mm)	0.49
	Area density (g/m^2)	206
C	Nylon/Spandex	67/33
	Thickness (mm)	0.53
	Area density (g/m^2)	240
D	Nylon/Spandex	63/37
	Thickness (mm)	0.61
	Area density (g/m^2)	313

Table 3.3: Some application areas of commercial garments.

Head 	**Shoulder** 	**Head and Neck** 	**Foot** 
Briefs, Suits and Vests			
Sleeved Body Brief 	**Sleeveless Suit to Ankle Knee** 	**Sleeved Suit to Toe or Ankle** 	

3.2 Antimicrobial Chemical Agents

Silver nitrate was obtained from Dow Chemical, silver chloride and Triclosan were obtained from Ciba (Hunstman Int.), silver biocide embedded in titanium dioxide crystal was obtained from Ruco Bac, Quat-Silane was obtained from Aegis Microbeshield, and PHMB was obtained from Rudolf Venture.

3.3 Auxiliary Chemicals

As auxiliary chemicals, epoxy resin and polyurethane were used for preparing silver nitrate antimicrobial solutions, cross-linker and catalyst were used for preparing PHMB antimicrobial solutions and silane was used for preparing QAC antimicrobial solutions.

3.4. Equipment

3.4.1 Pretreatment

3.4.1.1 Scouring

Ahiba Nuance machine was used for scouring of the fabric samples before pretreatment (Figure 3.4).

Figure 3.4: Ahiba Nuance machine used for scouring of the fabric samples.

3.4.1.2 Rinsing

Texcolour machine was used for rinsing the fabric samples before pretreatment (Figure 3.5).

Figure 3.5: Texcolour machine used for scouring of the fabric samples.

3.4.2 Antimicrobial treatment

3.4.2.1 Padding

Mathis HVF padder was used for the treatments of fabric samples with antimicrobial chemical agents (Figure 3.6).

Figure 3.6: Mathis HVF padder used for the antimicrobial treatments.

3.4.2.2 Exhaustion

Ahiba Nuance machines with 500ml and 1000ml beakers were used for the antimicrobial treatments of the fabric samples (Figure 3.7).

Figure 3.7: Ahiba Nuance machine used for antimicrobial treatment of the fabric samples.

3.4.3 Drying

Yamato convection oven was used for drying of the samples (Figure 3.8).

Figure 3.8: Yamato convection oven used for the drying of the fabric samples.

3.4.4 Curing

Mathis LTF stenter was used for curing of the fabric samples (Figure 3.9).

Figure 3.9: Mathis LTF stenter used for the curing of the samples.

3.4.5 Laundering

Atlas LaunderOmeter was used for laundering of the samples for wash durability.

3.5 Testing

3.5.1 Pressure measurements

A static mannequin and pressure garments designed for leg (from knee to knee) for each type of fabric were used for pressure measurements before and after antimicrobial treatments. Measurements were recorded using calibrated pressure sensors that were connected to a data acquisition and management software program by wireless transmitters [194-195]. Static mannequin and software program with wireless pressure sensors are shown in Figure 3.10 and Figure 3.11.

Figure 3.10: Static mannequin and pressure garments designed for leg (from ankle to knee).

Figure 3.11: Wireless pressure sensors used for pressure measurements.

3.5.2 Antimicrobial activity

AATCC Test Method 100 - 2004 "Assessment of Antibacterial Finishes on Textiles" was followed to determine antimicrobial activity [185]. Assessment of antibacterial activity finishes on textile material is determined by the degree of antibacterial activity intended in the use of such materials. Staphylococcus aureus ATCC 6538 (1.60 X10 ^{5} CFU/ml) microorganism was used as a test inoculum. Untreated control samples, treated samples and treated after 5, 10 and 50 washed samples were tested.

3.5.3 Wash durability

AATCC Test Method 61(2A) – 2010 "Colorfastness to Laundering Accelarated" was followed to evaluate the washing durability of the treated fabrics. Fabric samples were subjected to 5,10 and 50 consecutive launderings. Atlas LaunderOmeter was used and washing temperature was adjusted to 49^{o}C.

3.5.4 X-Ray photoelectron spectroscopy (XPS) analysis

The silver composition of the treated samples was observed using X-Ray Photoelectron Spectroscopy (XPS) analysis. XPS is a surface chemical analysis technique that can be used to analyze the surface chemistry of a material in its "as received" state, or after some treatment. XPS spectra are obtained by irradiating a material with a beam of X-rays while simultaneously measuring the kinetic energy and number of electrons that escape from the top 1 to 10 nm of the material being analyzed. XPS requires ultra high vacuum (UHV) conditions. XPS analysis was performed on three different sample sets to see the silver composition in the fabric. Untreated control samples were used to make a comparison.

3.5.5 Scanning electron microscope analysis (SEM)

SEM analysis were performed on three different sample sets to see if the silver solution appeared on the fabric and fiber surfaces. Images were acquired from a JEOL JSM 5900-LV scanning electron microscope using an accelerating voltage of 15 kV. Specimens were mounted on aluminum stubs using conductive carbon tape. They were then coated with gold/palladium using a Hummer^{TM} 6.2 Sputter Coating System (Anatech, CA, USA) to obtain a conductive coating about 100 Å thick. Untreated control samples were used to make a comparison.

3.5.6 Fourier transform infrared spectroscopy (FTIR)

In order to identify the infrared absorption spectrum and detect any changes in the structure of the treated samples with antimicrobial chemical agents during treatment, treated samples were scanned using a Nicolet Nexus 470 Spectrophotometer with AVATAR Omni Sampler for Attenuated Total Reflectance (ATR) mode. The specimen was mounted onto the surface of the Germanium (Ge) crystal in the ATR assembly. A total of 64 scans were aggregated between 1000 cm^{-1} and 4000 cm^{-1} with each spectrum having a 4 cm^{-1} resolution. The aggregated scans showing the absorbance across the infrared spectrum was acquired using OMNIC™ software. Untreated control samples were also tested to make a comparison.

3.5.7 Physical and mechanical properties

The physical and mechanical properties were tested in terms of air permeability, stiffness (CD,MD), bursting strength, drapeability, time dependent fabric growth and porosity properties were tested in order to evaluate the wear performances of burn

pressure garments which are worn for up to two years. They should also protect their wear performances after antimicrobial treatments. So the tests were also conducted for the treated samples.

Fraiser Air Permeability tester was used following ASTM D737 to test air permeability of the fabric samples [186]. Stiffness Cloth Tester, IDM Instrument was used to test stiffness of the fabric samples in CD and MD by following ASTM D5732 [187]. Ball Burst Scott Tester was used to test bursting strength following ASTM D3787 [188]. Cusick Drapemeter was used to test drapeability of the fabric samples by following BS 5058 [189]. ASTM D2594 Test Method was used to test the time dependent fabric growth of knitted fabrics [190].

3.5.8 Comfort properties

The thermophysiological properties were tested by following ASTM F-1868 Test Method to evaluate the comfort performance of the burn garments which are worn for up to two years [191].

Pressure garments should protect their thermophysiological comfort properties before and after antimicrobial treatments. For this, untreated and treated fabric samples were tested in terms of thermal resistance (Rct) and isolation properties (clo unit).

3.6 Experimental Methods

3.6.1 Pretreatment of fabric samples

The samples were conditioned for 24 hours at 20^{o}C, 65% relative humidity in the physical testing lab. For scouring, 4000ml stock solution was prepared with 0.5g/l sequestening agent (Questial), 2g/l soda ash and 2g/l non-ionic detergent (Triton-X). The samples were washed at 80^{o}C for 1h using Ahiba Nuance lab machine and rinsed at 38^{o}C for 1,5h using Texcolor machine. The samples were dried at 50^{o}C for 30 min using Yamato mechanical convection oven DKN 810. For scouring the samples Dupont procedure for synthetic fabrics with lycra was followed (Figure 3.12) [193].

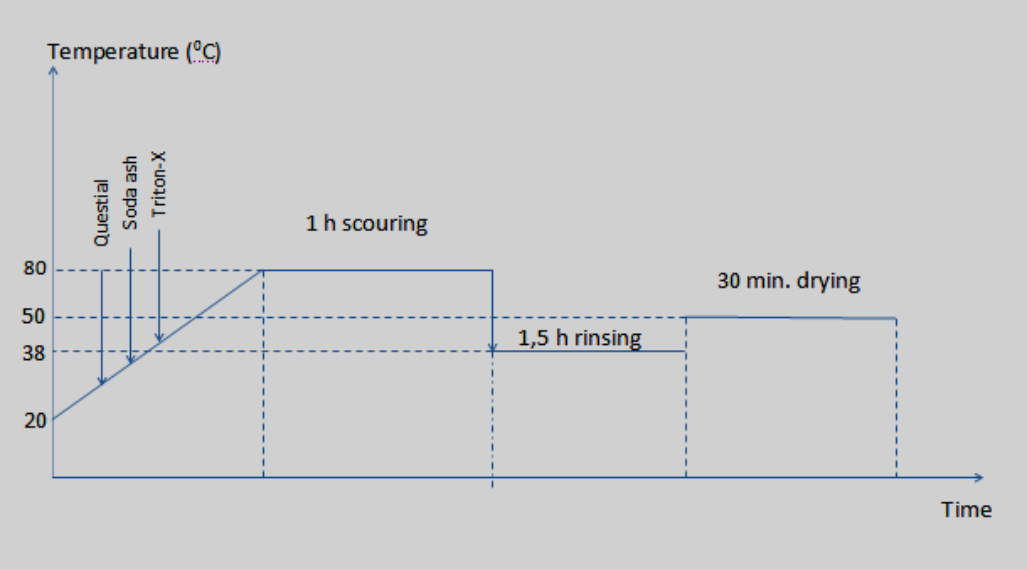


Figure 3.12: Scouring of fabric samples before treatment.

3.6.2 Treatment of fabric samples with antimicrobial chemical agents

3.6.2.1 Treatment of fabric samples with silver nitrate antimicrobial agents

Pad-dry-cure method was used for to apply silver nitrate antimicrobial solution by using a laboratory type padding machine. The fabrics were squeezed to a wet pickup of 67 % for powernet warp knitted fabrics, 46,5 % for flat warp knitted fabrics and 63% for weft knitted fabrics. The padding temperature was 20°C, the pressure was 1 bar and the machine speed was 1,5 m/min. A laboratory dryer was used for the drying and curing at 70°C for 10 min. The antimicrobial solutions were fixed at pH9 levels. The samples were treated with 0.6% silver nitrate antimicrobial chemical agent. The detailed flow chart of antimicrobial treatment with silver nitrate is shown as in Figure 3.13.

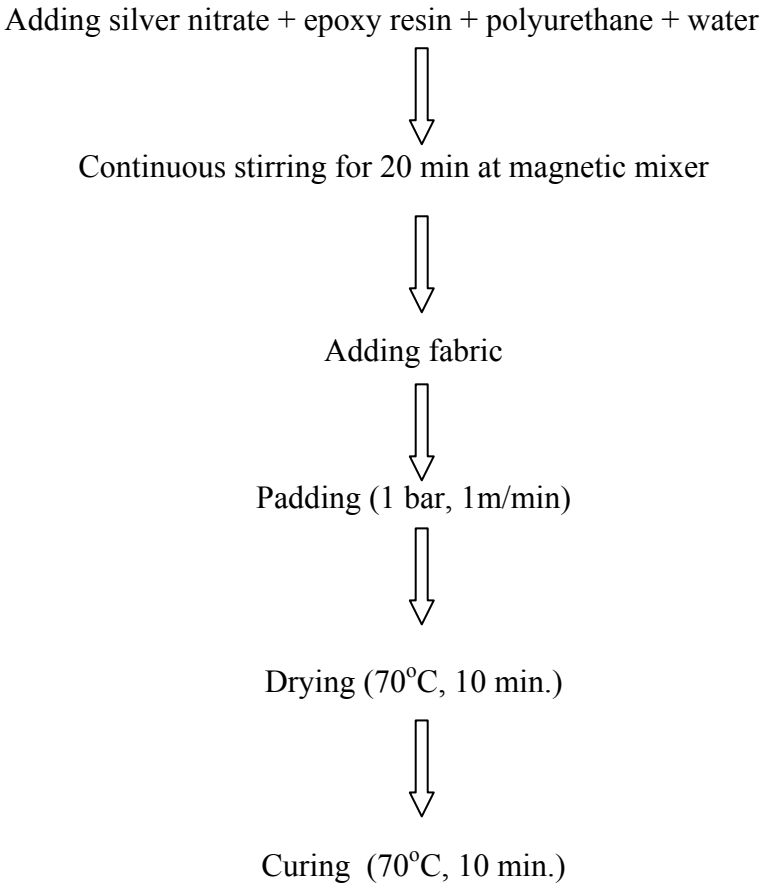


Figure 3.13: Flow chart of antimicrobial treatment with silver nitrate.

3.6.2.2 Treatment of fabric samples with Quat-Silane antimicrobial agents

Pad-dry-cure method was used to apply Quat-Silane antimicrobial by using a laboratory type padding machine. The fabrics were squeezed to a wet pickup of 80 % for powernet warp knitted fabrics, 46 % for flat warp knitted fabrics and 52 % for weft knitted fabrics. The padding temperature was 20°C, the pressure was 1 bar and the machine speed was 1,5 m/min. a laboratory dryer was used for drying and curing at 110 °C for 10 min. The samples were treated with 2% active Quat-Silane antimicrobial agent. The detailed flow chart of antimicrobial treatment with Quat-Silane is shown as in Figure 3.14.

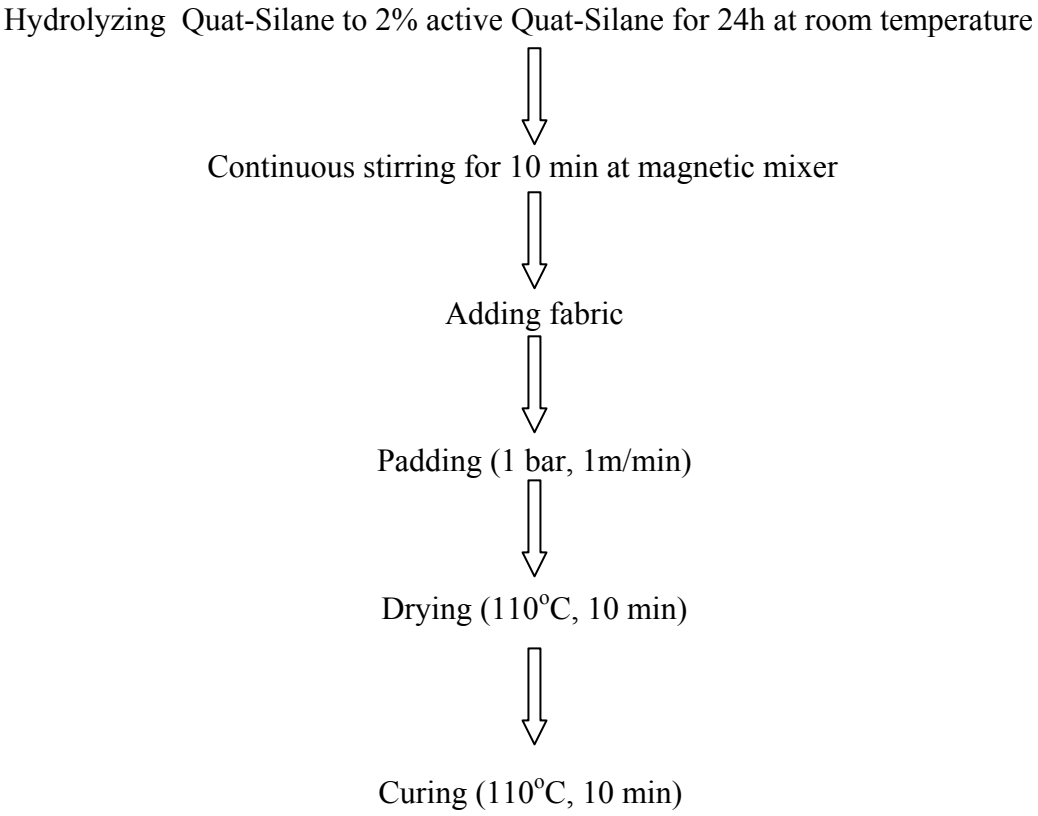


Figure 3.14: Flow chart of antimicrobial treatment with Quat-Silane.

3.6.2.3 Treatment of fabric samples with silver biocide antimicrobial agents

Pad-dry-cure method was used to apply silver biocide embedded in titanium dioxide crystal, with pH7, solution by using a laboratory type padding machine. The fabrics were squeezed to a wet pickup of 63 % for powernet warp knitted fabrics, 45 % for flat warp knitted fabrics and 62 % for weft knitted fabrics. The padding temperature was 20°C, the pressure was 1 bar and the machine speed was 1,5 m/min. A laboratory dryer was used for drying at 130°C for 1min and curing at 160°C for 1 min. The samples were treated with 0.5% silver biocide embedded in titanium dioxide crystal agent. The detailed flow chart of antimicrobial treatment with silver biocide is shown as in Figure 3.15.

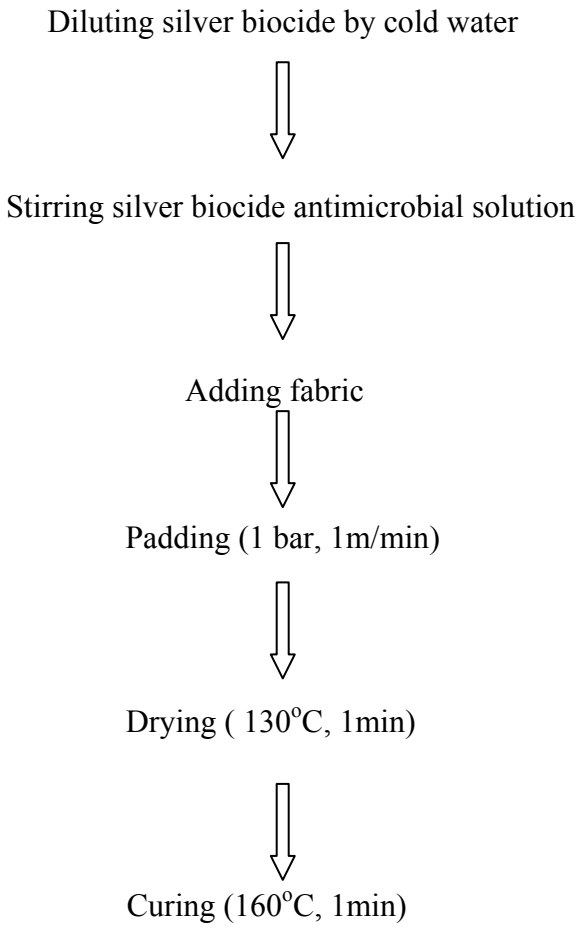


Figure 3.15: Flow chart of antimicrobial treatment with silver biocide.

3.6.2.4 Treatment of fabric samples with Triclosan antimicrobial agents

Exhaustion method was used to apply Triclosan antimicrobial by using a laboratory type Ahiba Nuance machine. The fabrics were squeezed to a wet pickup of 68 % for powernet warp knitted fabrics, 47 % for flat warp knitted fabrics and 50 % for weft knitted fabrics. The exhaustion temperature was 100°C, the bath temperature was 20°C, and 6 pH of the solution. The samples were treated for 30min. for 1h. A laboratory dryer was used for drying and curing at 100°C for 2 min. The samples were treated with 0.04% Triclosan antimicrobial agent. The detailed flow chart of antimicrobial treatment with Triclosan is shown as in Figure 3.16.

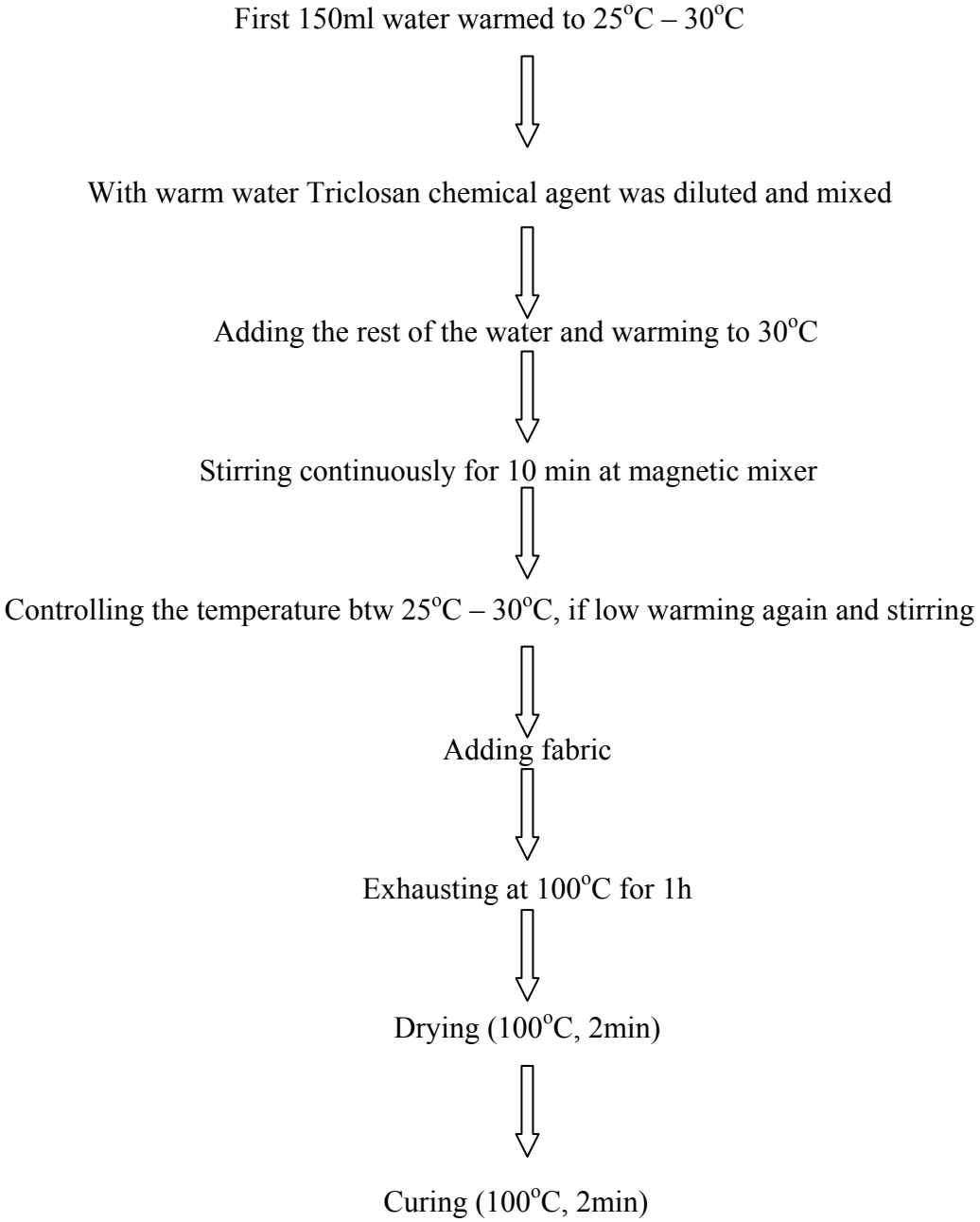


Figure 3.16: Flow chart of antimicrobial treatment with Triclosan.

3.6.2.5 Treatment of fabric samples with silver chloride antimicrobial agents

Pad-dry-cure method was used to apply silver chloride antimicrobial by using a laboratory type padding machine, with temperature at 20°C and 5.5pH. The fabrics were squeezed to a wet pickup of 75 % for powernet warp knitted fabrics, 44 % for flat warp knitted fabrics and 58 % for weft knitted fabrics. The padding temperature was 20°C, the pressure was 1 bar and the machine speed was 1,5 m/min. A laboratory dryer was used for drying at 130°C for 1min and curing at 160°C for 1 min. The samples were treated with 0.16% silver chloride antimicrobial agent. The

detailed flow chart of antimicrobial treatment with silver chloride is shown as in Figure 3.17.

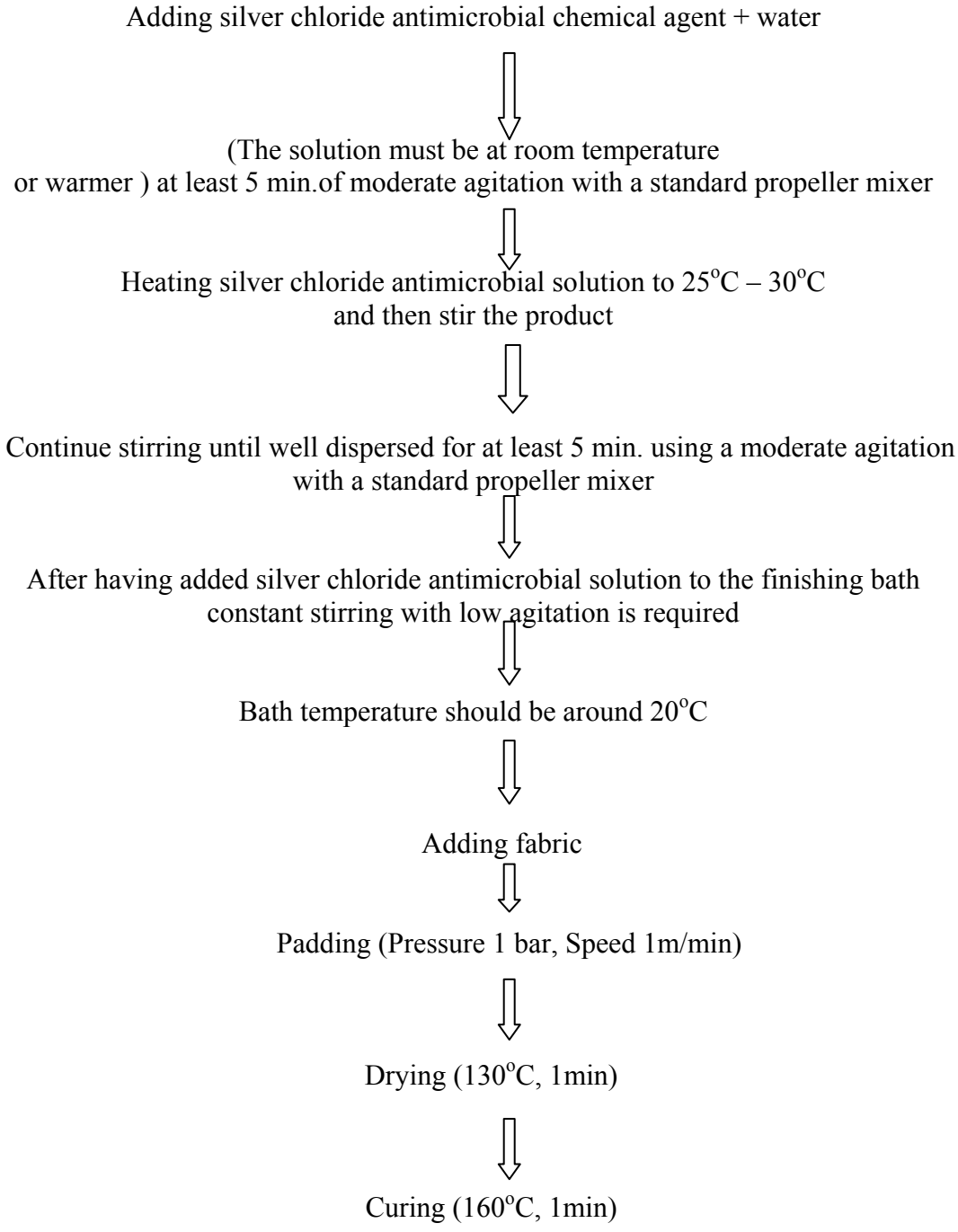


Figure 3.17: Flow chart of antimicrobial treatment with silver chloride.

3.6.2.6 Treatment of fabric samples with PHMB antimicrobial agents

Pad-dry-cure method was used to apply PHMB antimicrobial by using a laboratory type padding machine, with temperature at 40^{o}C and 6.5pH. The fabrics were squeezed to a wet pickup of 53 % for powernet warp knitted fabrics, 66 % for flat warp knitted fabrics and 84 % for weft knitted fabrics. The padding temperature was 20^{o}C, the pressure was 1 bar and the machine speed was 1,5 m/min. A laboratory dryer was used for drying at 100^{o}C for 1min and curing at 150^{o}C for 1.5 min. The samples were treated with 4% PHMB antimicrobial agent. The detailed flow chart of antimicrobial treatment with silver chloride is shown as in Figure 3.18.

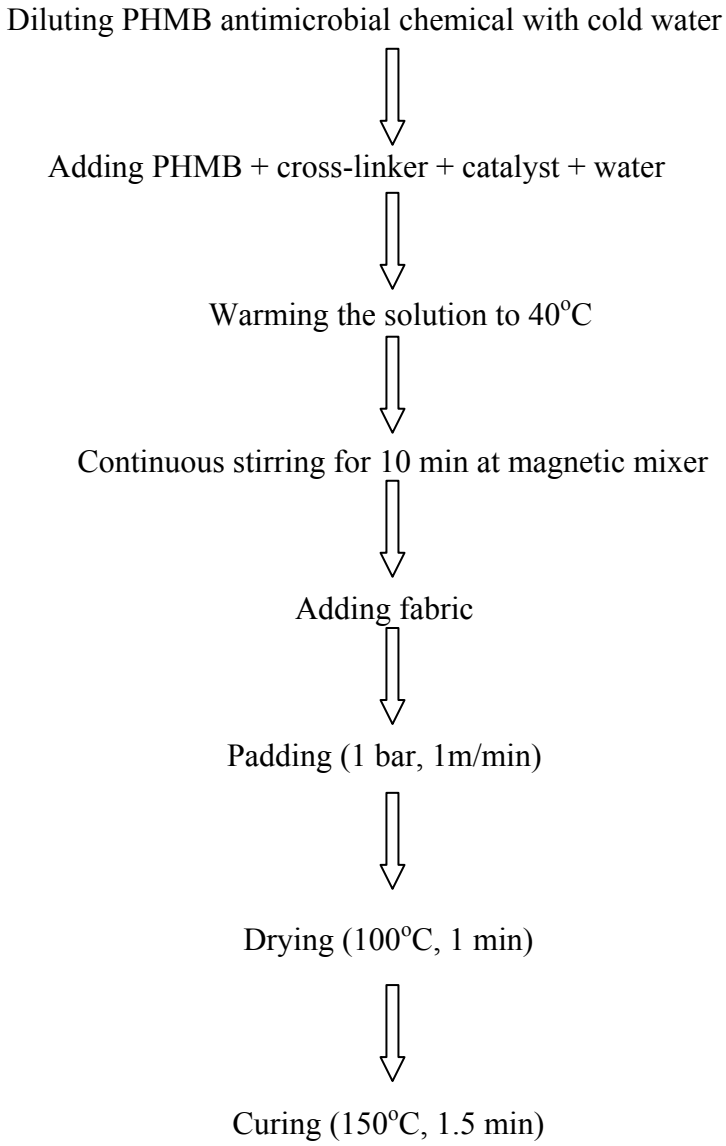


Figure 3.18: Flow chart of antimicrobial treatment with PHMB.

3.6.3 Antimicrobial treatment procedure variables

3.6.3.1 Antimicrobial solution pH

The ability of nylon to absorb antimicrobial solution is governed by the pH of the antimicrobial solution. Aqueous solutions of silver must be adjusted to a pH between 5 and 9. At this pH range strong binding occurs. Triclosan is adjusted to pH6 for strong binding to the nylon fibers. At pH5 the Quat-Silane aqueous solution is able to bind to the nylon fibers.

If the solution is below pH5, the PHMB is unable to bind to the nylon fibres. Above pH6, strong binding occurs. Aqueous solutions of PHMB are adjusted to a pH of above 6 before use. Sodium hydroxide or sodium carbonate can be used to raise the pH. The antimicrobial solution pH for each antimicrobial chemical is given in Figure 3.19.

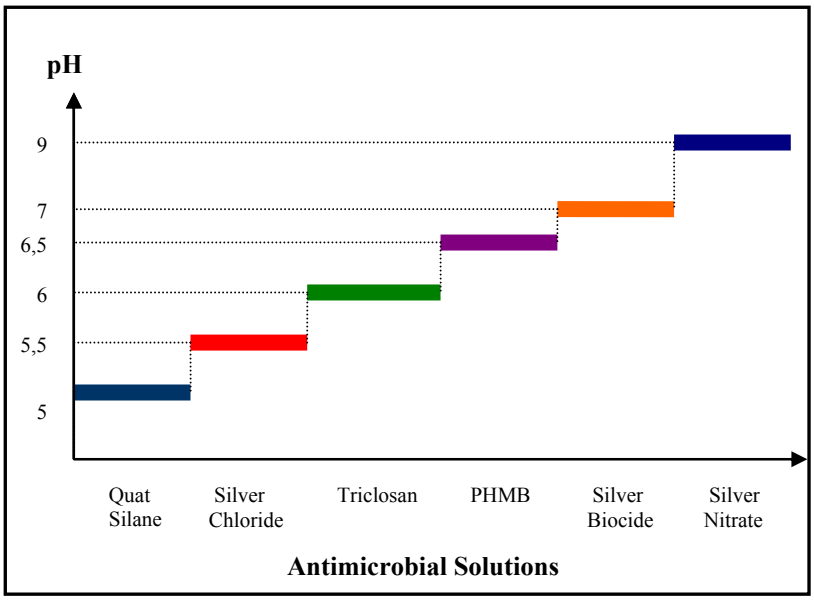


Figure 3.19: pH for each antimicrobial treatment procedure.

3.6.3.2 Antimicrobial solution temperature (^{o}C)

The optimum condition for application of the dilute antimicrobial solutions is temperature of approximately 20^{o}C for silver, Triclosan and quat-silane antimicrobial solutions and 40^{o}C for PHMB antimicrobial solutions. Aqueous solutions of antimicrobial chemicals are stable at these temperatures. The antimicrobial solution temperatures are given in Figure 3.20.

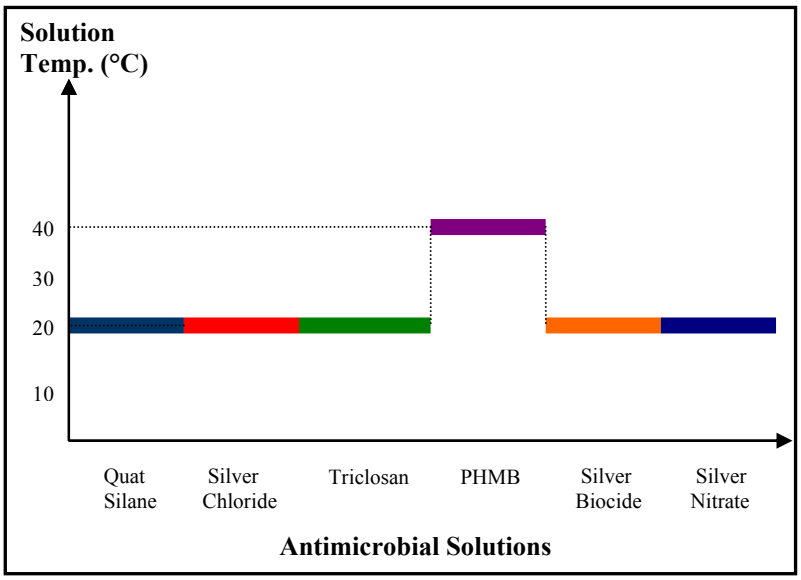


Figure 3.20: Solution temperatures (^{o}C) for each antimicrobial treatment procedure.

3.6.3.3 Antimicrobial treatment temperature (^{o}C)

The Triclosan antimicrobial treatment is compatible with exhaustion method at 100^{o}C treatment temperature. Silver, quat–silane and PHMB solutions are compatible with padding method at 20^{o}C. The treatment temperatures for each antimicrobial solutions with treatment procedures are given in Figure 3.21.

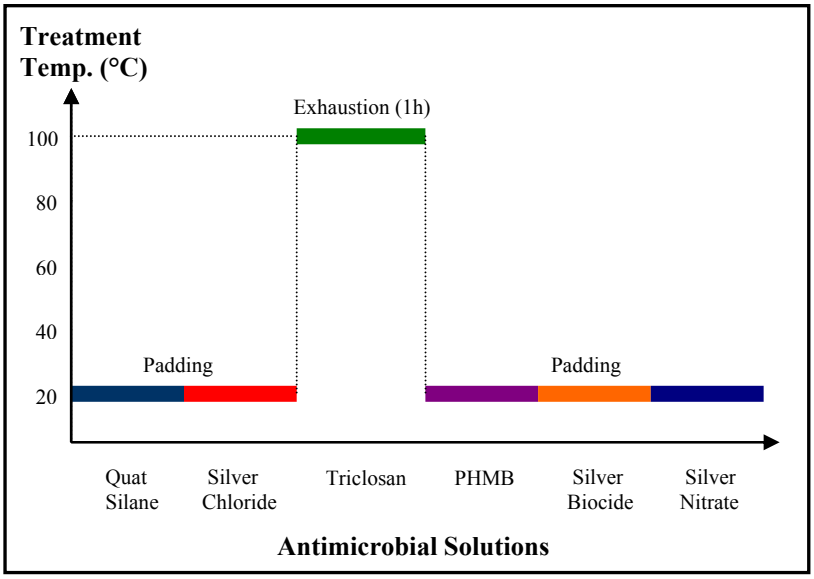


Figure 3.21: Treatment temperatures (^{o}C) for each antimicrobial treatment procedure.

3.6.3.4 Antimicrobial treatment drying temperature (^{o}C)

Appropriate drying temperatures for each antimicrobial treatment are used as in Figure 3.22. 100^{o}C drying temperature is used for 2 min for Triclosan and 1 min for PHMB treatments, 130^{o}C drying temperature is used for 1 min for silver chloride and silver biocide (silver embedded in titanium dioxide crystal), 110^{o}C drying temperature is used for 10 min for quat-silane treatment and 70^{o}C drying temperature is used for 10 min. for silver nitrate treatment. In this step, excess water is removed from the treated fabrics by considering the polymer chemical stability temperatures.

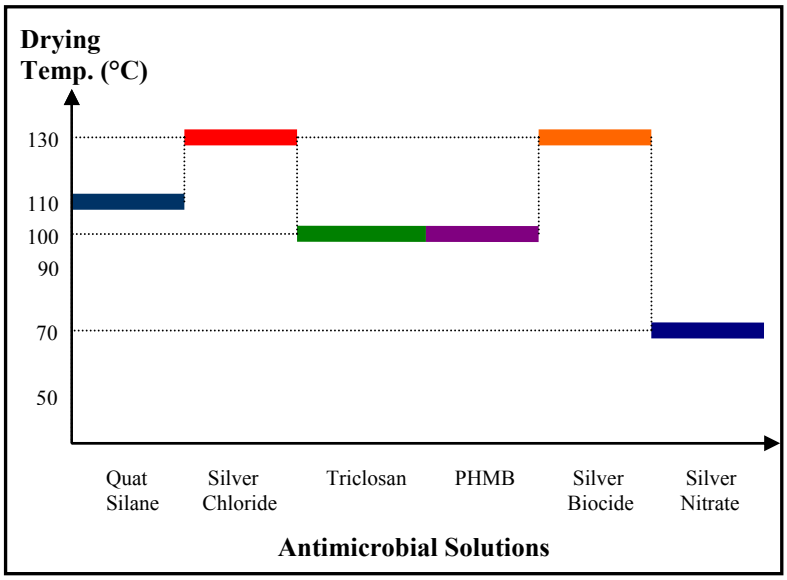


Figure 3.22: Drying temperatures (^{o}C) for each antimicrobial treatment procedure.

3.6.3.5 Antimicrobial treatment curing temperature (^{o}C)

Curing temperatures for each antimicrobial treatment are applied as in Figure 3.23. The fabric samples treated with silver nitrate solution are cured at 70^{o}C for 10 min, for fabric samples treated with quat-silane solution are cured at 110^{o}C for 10 min, fabric samples treated with silver biocide (silver embedded in titanium dioxide crystal) are cured at 130^{o}C for 1 min. 100^{o}C curing temperature is used for 2 min for Triclosan antimicrobial treatments, 160^{o}C curing temperature is used for 1 min for silver chloride antimicrobial treatments and 150^{o}C curing temperature is used for 1.5 min for PHMB antimicrobial treatments. The curing temperatures were varied according to application level of each antmicrobial chemical. This step is important for the homogenity bonding of the antimicrobial chemical in and on the surface of the fabric.

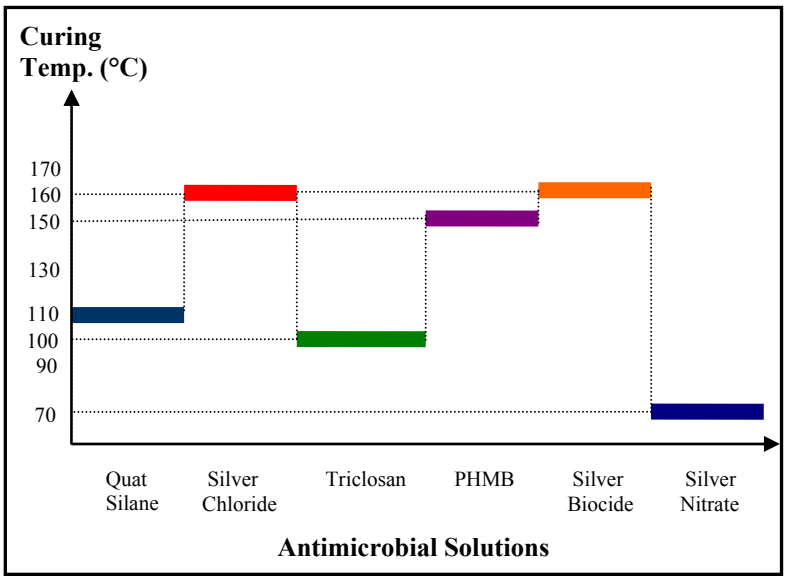


Figure 3.23: Curing temperatures (^{o}C) for each antimicrobial treatment procedure.

3.6.4 Pressure measurements

3.6.4.1 Wireless software program

For pressure measurements a Tekscan's Wireless Elf System was used including a hub and a transmitter (Figure 3.24). This system is ideal to measure forces without disturbing the dynamics of the test.

The Elf sensors use a resistive-based technology. The application of a force to the active sensing area of the sensor results in a change in the resistance of the sensing element in inverse proportion to the force applied. After a simple calibration is performed, this force can be displayed on the screen in the measurement units that is chosen, such as Pounds or Newton's.

Figure 3.24: Component identification for the pressure measurements.

3.6.4.2 Conditioning sensors

Exercising or conditioning a sensor before calibration and testing is essential in achieving accurate results. To condition a sensor, 110% of the test weight was placed on the sensor, and the sensor was allowed to stabilize, and then the weight was removed. This process was repeated four or five times. The interface between the sensor and the test subject material should be the same during conditioning as during calibration and actual testing.

3.6.4.3 Sensors

The *FlexiForce* sensor is an ultra-thin and flexible printed circuit. Sensors are available in three full-scale force ranges: *Low* (25 lbf), *Medium* (150 lbf), and *High* (1000 lbf). The "active sensing area" is a 0.375” diameter circle at the end of the sensor. The sensors are constructed of two layers of substrate, such as a polyester film. On each layer, a conductive material (silver) is applied, followed by a layer of pressure-sensitive ink. Adhesive is then used to laminate the two layers of substrate together to form the sensor. The "active sensing area" is defined by the silver circle on top of the pressure sensitive ink. Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads. FlexiForce B201 Sensors (one in each of the three offered force ranges: Low (0-25 lb); Medium (0-150 lb) and High (0-1000 lb) were used for this study (Figure 3.25).

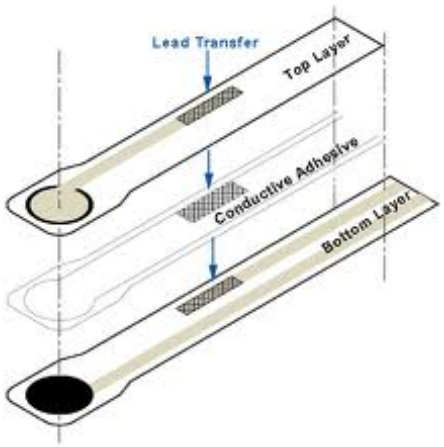


Figure 3.25: Wireless sensors for pressure measurements.

3.6.4.4 Calibration procedure

At this stage, each sensor was loaded with a known force as shown in Figure 3.26.

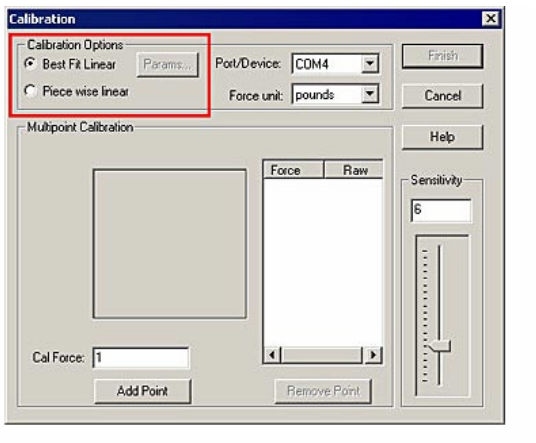


Figure 3.26: Loading force on the software program.

Best fit linear calibration was selected from the menu as shown in Figure 3.27. The gram Force unit was selected from the drop-down box (grams, kilograms, Newtons, pounds). The Add Point was clicked for each loads. And the steps were repeated as many known loads (Figure 3.28).

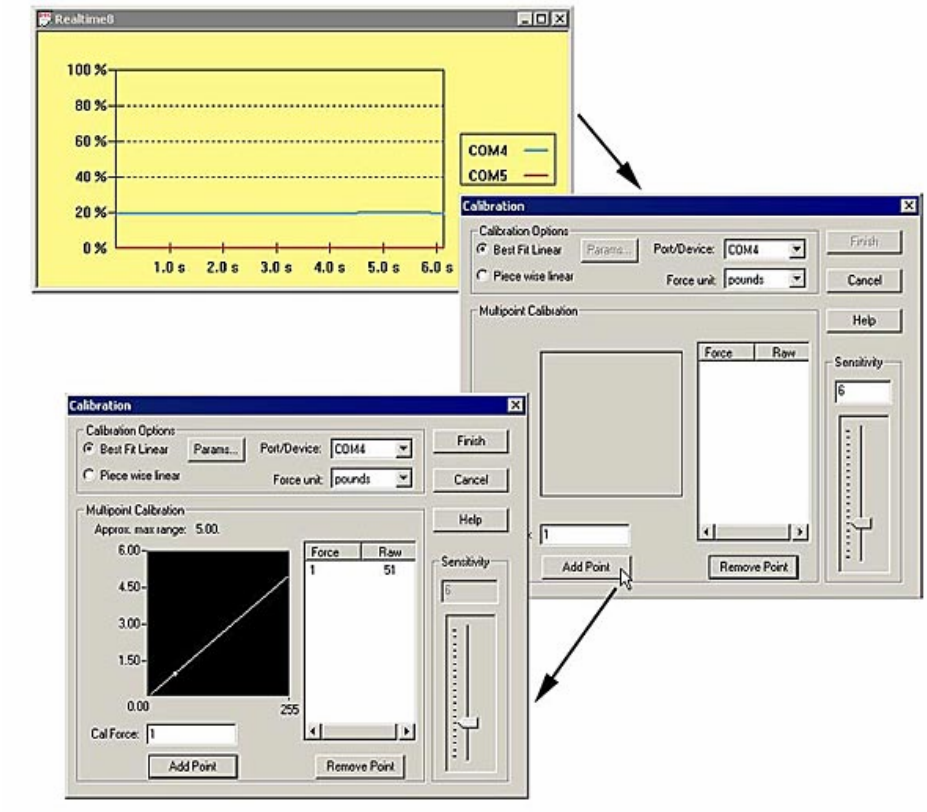


Figure 3.27: Adjusting best linear calibration.

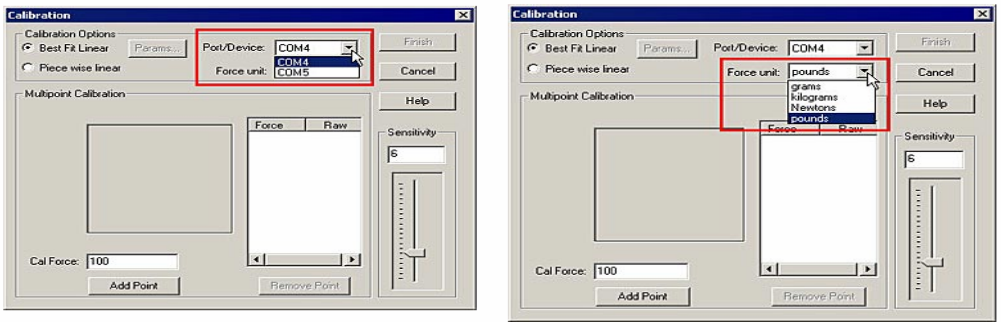


Figure 3.28: Calibration procedure of the pressure sensors.

3.6.4.5 The main window

The main window was displayed on the computer screen just before taking the pressures as shown in Figure 3.29.

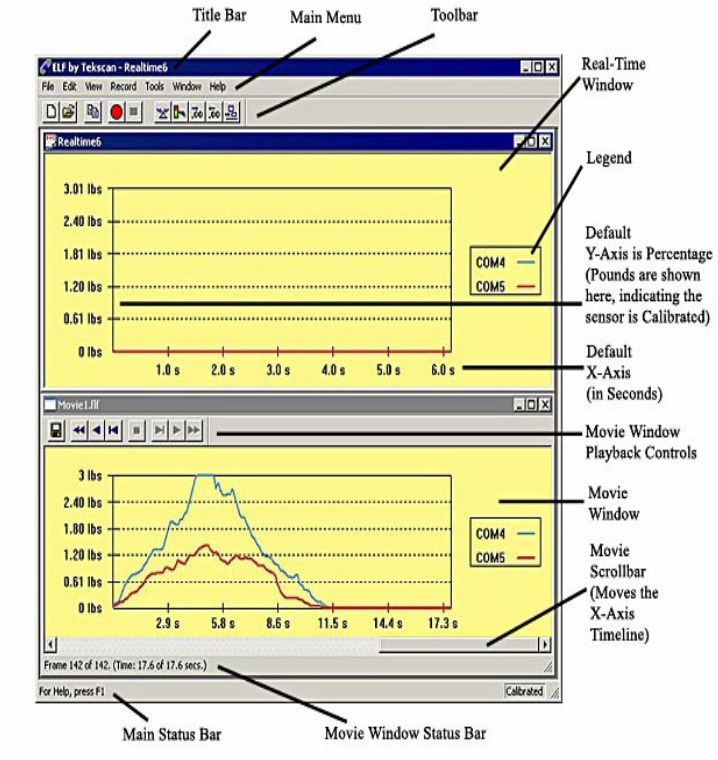


Figure 3.29: The main window of the wireless software program.

3.6.4.6 Taking pressures on pressure garments by wireless sensors

The pressure garments were designed by using high stretch nylon/spandex fabrics in weft and warp knitted structures. The measurements were taken on each garment from calf and ankle before and after the treatment as shown in Figures (3.30 - 3.31).

Figure 3.30: Taking pressures from calf by wireless pressure sensors.

Figure 3.31: Taking pressures from ankle by wireless pressure sensors.

3.6.5 Statistical Analysis

The statistical analysis of the experimental data was performed using JMP version 8.0.2 software package (SAS Institute, Inc., Cary, NC). The statistical analysis includes the analysis of variance (ANOVA). For the one-way and two-way ANOVA, p-values less than 0.05 were considered statistically significant. Some of the data are also presented as avarage ± standard deviation and some of the data are analyzed by regression analysis to calculate the coefficient of determination R^2.

4. RESULTS AND DISCUSSION

4.1 Pressure Measurements

The pressure measurements were taken from calf and ankle before and after each treatment. Before the treatment, the pressures were taken between 5.0mmHg – 5.7mmHg. This range is in the required medical range. Higher pressures were measured for ankle before and after treatment.

The La Place equation was originally described in 1805 to define the relationship between the pressure of a closed elastic membrane and the tension within the membrane. La Place's law states that sub-bandage pressure (P) is directly proportional to bandage tension (T) and inversely proportional to the circumference (C) of the limb to which it is applied (Eq. 4.1) [196-198]. As the circumference of the limb increases, the pressure decreases (Figure 4.1)

$$P = \alpha \frac{T/W}{R} \qquad (4.1)$$

P is the interface pressure (in mmHg or hPa), T/W is the tension (N) by width unit, R is the radius of the leg (m), α is the proportionality coefficient.

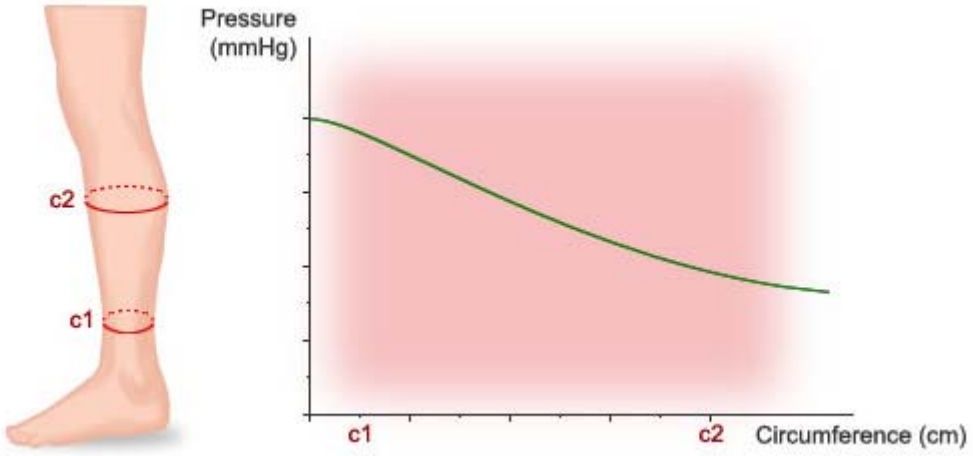


Figure 4.1: Illustration of Laplace's Law.

Pressures were taken from calf and ankle after each antimicrobial agent procedure for all types of designed pressure garments. Final pressures exerted on the limb were calculated by taking the mean pressures of calf and ankle.

4.1.1 Silver Nitrate antimicrobial agent

After treating the samples with silver nitrate antimicrobial agent, the pressures were taken between 5.4mmHg – 6.7mmHg (Table 4.1).

Table 4.1: Mean scores of pressures (mmHg) for the treated samples with silver nitrate antimicrobial agent procedure.

Name of Location	Pressures (mmHg)			Increase in Pressure %
	Fabric Samples	Before Treatment	After Treatment	
Ankle	Powernet	5.2	5.8	11.5
	Flat Warp Knitted	5.4	6.3	16.6
	Weft Knitted	5.8	6.7	15.5
Calf	Powernet	4.8	5.4	12.5
	Flat Warp Knitted	5.0	5.6	12.0
	Weft Knitted	5.6	5.9	5.3

Mean scores of final pressures showed a small significant increase for fabric samples after treated with silver nitrate antimicrobial chemical agents (Table 4.2). Weft knitted fabrics gave the highest pressure values before and after antimicrobial

treatment (Figure 4.2). This is attributed to more elastic structure of weft knitted fabrics than warp knitted fabrics which causes a small significant shrinkage during processes.

Table 4.2: Mean scores of final pressures (mmHg) and the increase in final pressure for the treated samples with silver nitrate antimicrobial agent procedure.

Fabric Samples	Final Pressures (mmHg)		Increase in Pressure %
	Before Treatment	After Treatment	
Powernet	5.0	5.6	12.0
Flat Warp Knitted	5.2	5.9	13.5
Weft Knitted	5.7	6.3	10.5

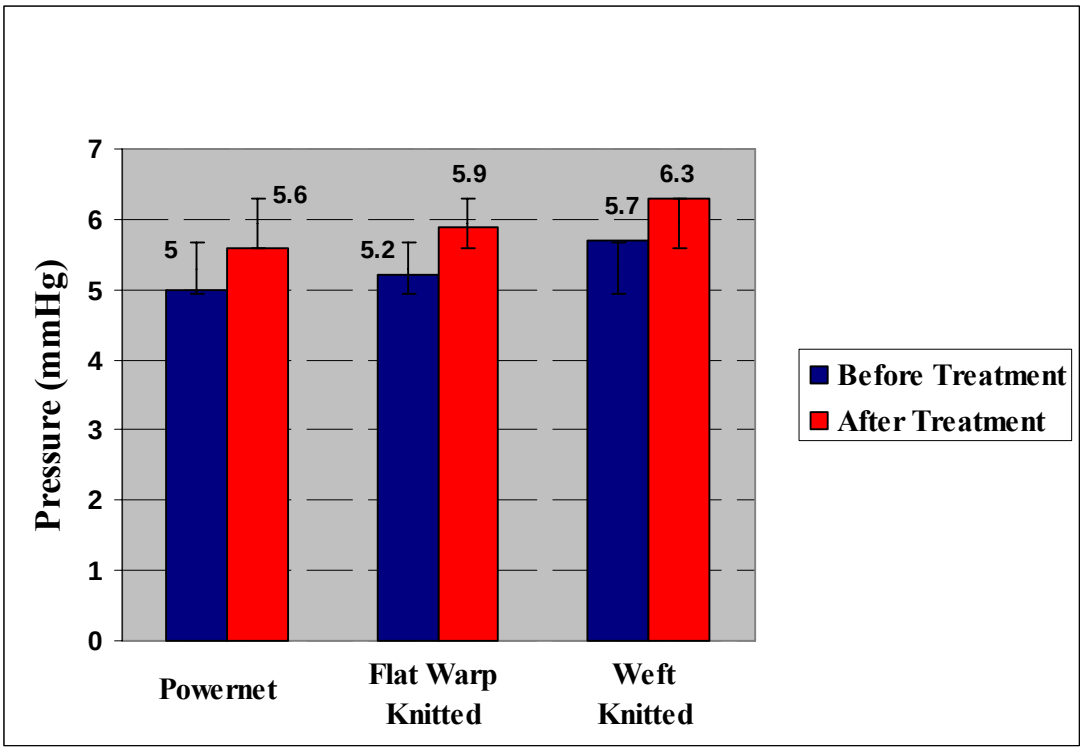


Figure 4.2: Mean scores of final pressures (mmHg) for the treated samples with silver nitrate antimicrobial agent procedure **(**Error bars: ± standard deviation).

4.1.2 Quat-Silane antimicrobial agent

After treating the samples with Quat-Silane antimicrobial agent, the mean scores of pressures were taken between 5.0mmHg – 6.0mmHg (Table 4.3).

Table 4.3: Mean scores of pressures (mmHg) for the treated samples with Quat-Silane antimicrobial agent procedure.

Name of Location	Pressures (mmHg)			Increase in Pressure %
	Fabric Samples	Before Treatment	After Treatment	
Ankle	Powernet	5.2	5.4	3.8
	Flat Warp Knitted	5.4	5.7	5.6
	Weft Knitted	5.8	6.0	3.4
Calf	Powernet	4.8	5.0	4.2
	Flat Warp Knitted	5.0	5.2	4.0
	Weft Knitted	5.6	5.9	5.4

Mean scores of final pressures showed a small siginificant increase for fabric samples after treated with quat-silane antimicrobial chemical agents (Table 4.4). Weft knitted fabrics gave the highest pressure values before and after antimicrobial treatment (Figure 4.3). This is attributed to more elastic structure of weft knitted fabrics than warp knitted fabrics which causes a small siginificant shrinkage during processes.

Table 4.4: Mean scores of final pressures (mmHg) and the increase in final pressure for the treated samples with Quat Silane antimicrobial agent procedure.

Fabric Samples	Final Pressures (mmHg)		Increase in Pressure %
	Before Treatment	After Treatment	
Powernet	5.0	5.2	4.0
Flat Warp Knitted	5.2	5.5	5.8
Weft Knitted	5.7	6.0	5.3

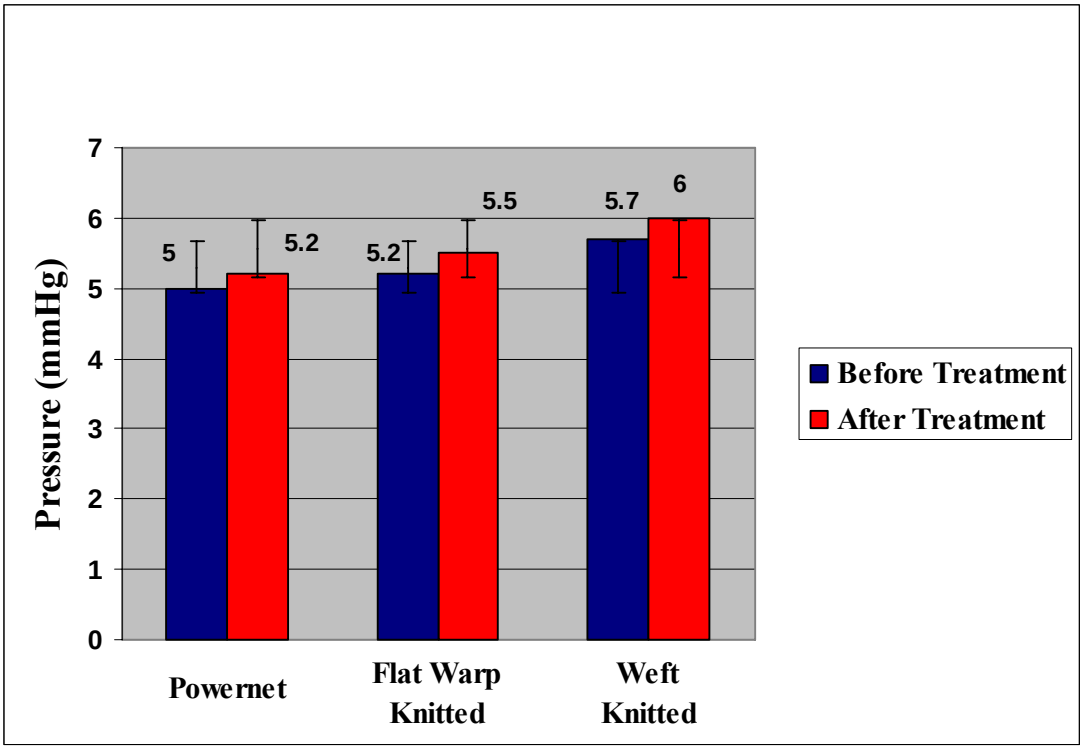


Figure 4.3: Mean scores of final pressures (mmHg) for the treated samples with Quat-Silane antimicrobial agent procedure **(**Error bars: ± standard deviation).

4.1.3 Silver Biocide antimicrobial agent

After treating the samples with silver biocide antimicrobial agent, the mean scores of pressures were taken between 5.0mmHg – 6.1mmHg (Table 4.5).

Table 4.5: Mean scores of pressures (mmHg) for the treated samples with silver embedded in titanium dioxide crystal antimicrobial agent procedure.

Name of Location	Pressures (mmHg)			Increase in Pressure %
	Fabric Samples	Before Treatment	After Treatment	
Ankle	Powernet	5.2	5.4	3.8
	Flat Warp Knitted	5.4	5.5	1.8
	Weft Knitted	5.8	6.1	5.2
Calf	Powernet	4.8	5.0	4.2
	Flat Warp Knitted	5.0	5.2	4.0
	Weft Knitted	5.6	5.8	3.6

Mean scores of final pressures showed a small siginificant increase for fabric samples after treated with silver titanium dioxide antimicrobial chemical agents (Table 4.6). Weft knitted fabrics gave the highest pressure values before and after antimicrobial treatment (Figure 4.4). This is attributed to more elastic structure of weft knitted fabrics than warp knitted fabrics which causes a small significant shrinkage during processes.

Table 4.6: Mean scores of final pressures(mmHg) and the increase in final pressures for the treated samples with silver embedded in titanium dioxide crystal antimicrobial agent procedure.

Fabric Samples	Final Pressures (mmHg)		Increase in Pressure %
	Before Treatment	After Treatment	
Powernet	5.0	5.2	4.0
Flat Warp Knitted	5.2	5.4	3.8
Weft Knitted	5.7	5.9	3.5

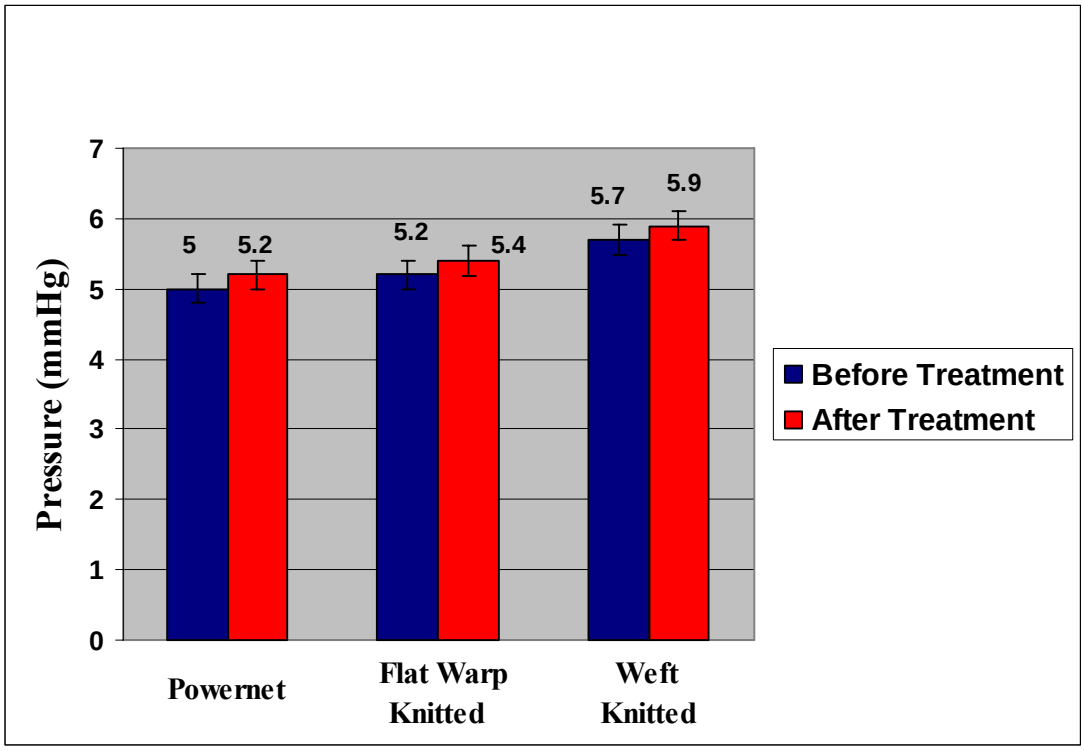


Figure 4.4: Mean scores of final pressures (mmHg) for the treated samples with Silver Biocide antimicrobial agent procedure (Error bars: ± standard deviation).

4.1.4 Triclosan antimicrobial agent

After treating the samples with Triclosan antimicrobial agent, the mean scores of pressures were taken between 5.4mmHg – 6.4mmHg (Table 4.7).

Table 4.7: Mean scores for pressures (mmHg) for the treated samples with Triclosan antimicrobial agent procedure.

Name of Location	Pressures (mmHg)			Increase in Pressure %
	Fabric Samples	Before Treatment	After Treatment	
Ankle	Powernet	5.2	5.6	7.7
	Flat Warp Knitted	5.4	6.0	11.1
	Weft Knitted	5.8	6.4	10.3
Calf	Powernet	4.8	5.4	12.5
	Flat Warp Knitted	5.0	5.7	14.0
	Weft Knitted	5.6	6.2	10.7

Mean scores of final pressures showed a small siginificant increase for fabric samples after treated with Triclosan antimicrobial chemical agents (Table 4.8). Weft knitted fabrics gave the highest pressure values before and after antimicrobial treatment (Figure 4.5). This is attributed to more elastic structure of weft knitted fabrics than warp knitted fabrics which causes a small significant shrinkage during processes.

Table 4.8: Mean scores of final pressures (mmHg) and the increase in final pressures for the treated samples with Triclosan antimicrobial agent procedure.

Fabric Samples	Final Pressures (mmHg)		Increase in Pressure %
	Before Treatment	After Treatment	
Powernet	5.0	5.5	10.0
Flat Warp Knitted	5.2	5.9	13.5
Weft Knitted	5.7	6.3	10.5

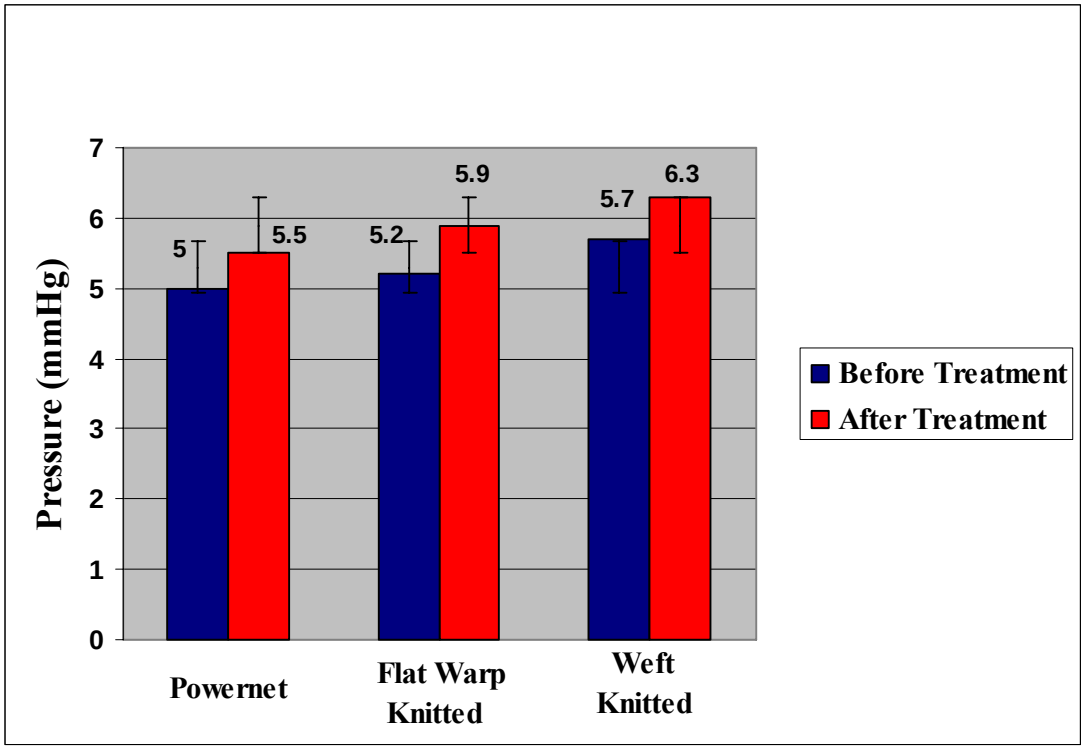


Figure 4.5: Mean scores of final pressures (mmHg) for the treated samples with Triclosan antimicrobial agent procedure **(**Error bars: ± standard deviation).

4.1.5. Silver Chloride antimicrobial agent

After treating the samples with silver chloride antimicrobial agent, the mean scores of pressures were taken between 5.0mmHg – 6.0mmHg (Table 4.9).

Table 4.9: Mean scores of pressures (mmHg) for the treated samples with silver chloride antimicrobial agent procedure.

Name of Location	Pressures (mmHg)			Increase in Pressure %
	Fabric Samples	Before Treatment	After Treatment	
Ankle	Powernet	5.2	5.4	3.8
	Flat Warp Knitted	5.4	5.5	1.8
	Weft Knitted	5.8	6.0	3.4
Calf	Powernet	4.8	5.0	4.2
	Flat Warp Knitted	5.0	5.1	2.0
	Weft Knitted	5.6	5.8	3.6

Final pressures showed a small significant increase for fabric samples after treated with silver chloride antimicrobial chemical agents (Table 4.10). Weft knitted fabrics gave the highest pressure values before and after antimicrobial treatments (Figure 4.6). This is attributed to more elastic structure of weft knitted fabrics than warp knitted fabrics which causes a small significant shrinkage during processes.

Table 4.10: Mean scores of final pressures (mmHg) and the increase in final pressures for the treated samples with silver chloride antimicrobial agent procedure.

Fabric Samples	Final Pressures (mmHg)		Increase in Pressure %
	Before Treatment	After Treatment	
Powernet	5.0	5.2	4.0
Flat Warp Knitted	5.2	5.3	2.0
Weft Knitted	5.7	5.9	3.5

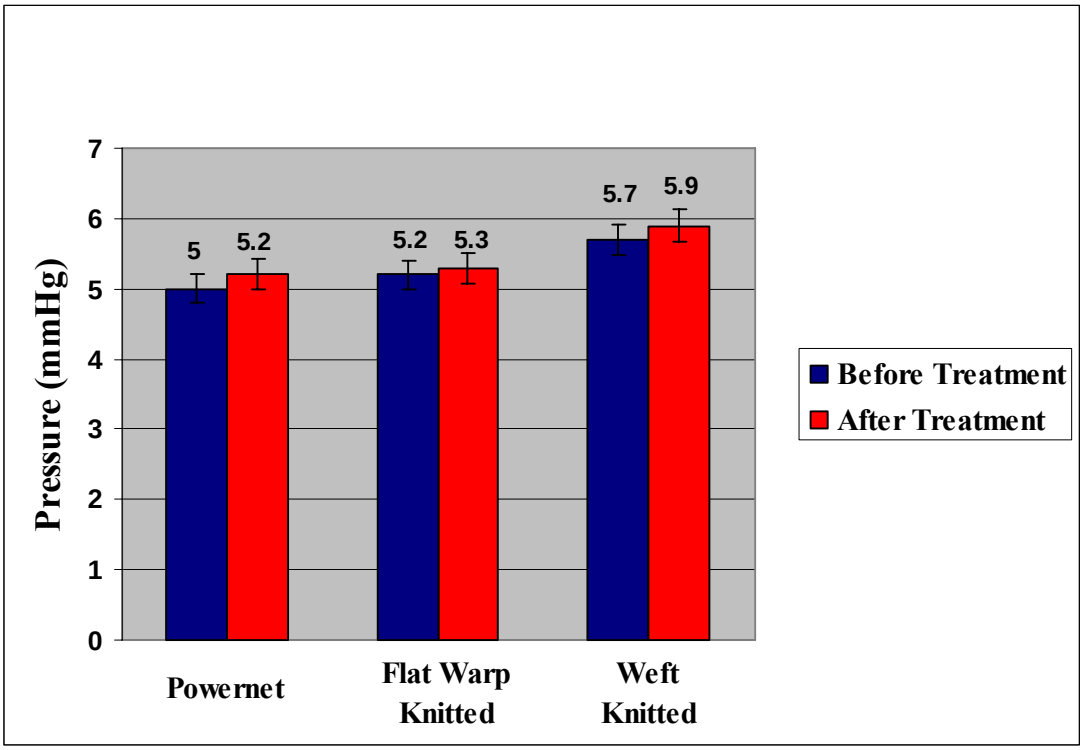


Figure 4.6: Mean scores of final pressures (mmHg) for the treated samples with silver chloride antimicrobial agent procedure (Error bars: ± standard deviation).

4.1.6 PHMB antimicrobial agent

After treating the samples with PHMB antimicrobial agent, the mean scores of pressures were taken between 5.2mmHg – 6.1mmHg (Table 4.11).

Table 4.11: Mean scores of pressures (mmHg) for treated samples with PHMB antimicrobial agent procedure.

Name of Location	Pressures (mmHg)			Increase in Pressure %
	Fabric Samples	Before Treatment	After Treatment	
Ankle	Powernet	5.2	5.5	5.8
	Flat Warp Knitted	5.4	5.8	7.4
	Weft Knitted	5.8	6.1	5.2
Calf	Powernet	4.8	5.2	8.3
	Flat Warp Knitted	5.0	5.3	6.0
	Weft Knitted	5.6	6.0	7.1

Mean scores of final pressures showed a small significant increase for fabric samples after treated with PHMB antimicrobial chemical agents (Table 4.12). Weft knitted fabrics gave the highest pressure values before and after antimicrobial treatment (Figure 4.7). This is attributed to more elastic structure of weft knitted fabrics than warp knitted fabrics which causes a small significant shrinkage during processes.

Table 4.12: Mean scores of final pressures (mmHg) and the increase in final pressures for the treated samples with PHMB antimicrobial agent procedure.

Fabric Samples	Final Pressures (mmHg)		Increase in Pressure %
	Before Treatment	After Treatment	
Powernet	5.0	5.4	8.0
Flat Warp Knitted	5.2	5.6	7.7
Weft Knitted	5.7	6.0	5.3

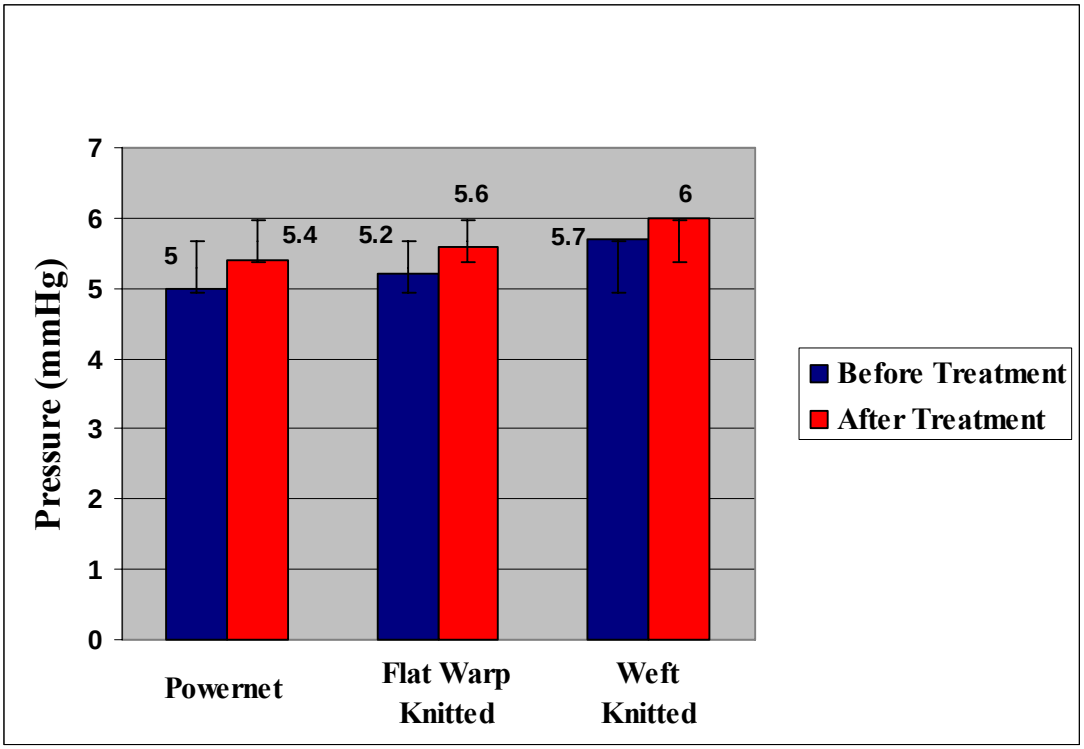


Figure 4.7: Mean scores of final pressures (mmHg) for the treated samples with PHMB antimicrobial agent procedure (Error bars: ± standard deviation).

A comparison of pressures (mmHg) and final pressures (mmHg) for each antimicrobial agent procedure are shown in Table 4.13 and Figure 4.8. Weft knitted fabrics gave higher pressures and powernet fabrics gave lower pressures after each antimicrobial procedure. This is attributed to more elastic structure of weft knitted fabrics than warp knitted fabrics which caused a small significant shrinkage during processing. Increase in pressure % is higher for fabrics treated with silver nitrate, Triclosan and PHMB. This is attributed to the auxiliary chemical used for each antimicrobial agent procedure. Use of epoxy resin and PU for silver nitrate agent procedure and cross-linker for PHMB agent procedure and using exhaustion treatment method for Triclosan antimicrobial agent procedure caused a little shrinkage resulting a little pressure increase in the fabric structures after antimicrobial treatments. Finally the pressures gathered are all in the expected medical range which show the success of the control of the antimicrobial agent procedures in terms of pressure measurements.

Table 4.13: A comparison of pressures (mmHg) from each treatment.

Antimicrobial Agent Procedure	Fabric Samples	Pressures (mmHg)		Increase in Pressure %
		Before Treatment	After Treatment	
Silver Nitrate	Powernet	5.0	5.6	12.0
	Flat Warp Knitted	5.2	5.9	13.5
	Weft Knitted	5.7	6.3	10.5
Quat- Silane	Powernet	5.0	5.2	4.0
	Flat Warp Knitted	5.2	5.5	5.8
	Weft Knitted	5.7	6.0	5.3
Silver Biocide	Powernet	5.0	5.2	4.0
	Flat Warp Knitted	5.2	5.4	3.8
	Weft Knitted	5.7	5.9	3.5
Triclosan	Powernet	5.0	5.5	10.0
	Flat Warp Knitted	5.2	5.9	13.5
	Weft Knitted	5.7	6.3	10.5
Silver Chloride	Powernet	5.0	5.2	4.0
	Flat Warp Knitted	5.2	5.3	2.0
	Weft Knitted	5.7	5.9	3.5
PHMB	Powernet	5.0	5.4	8.0
	Flat Warp Knitted	5.2	5.6	7.7
	Weft Knitted	5.7	6.0	5.3

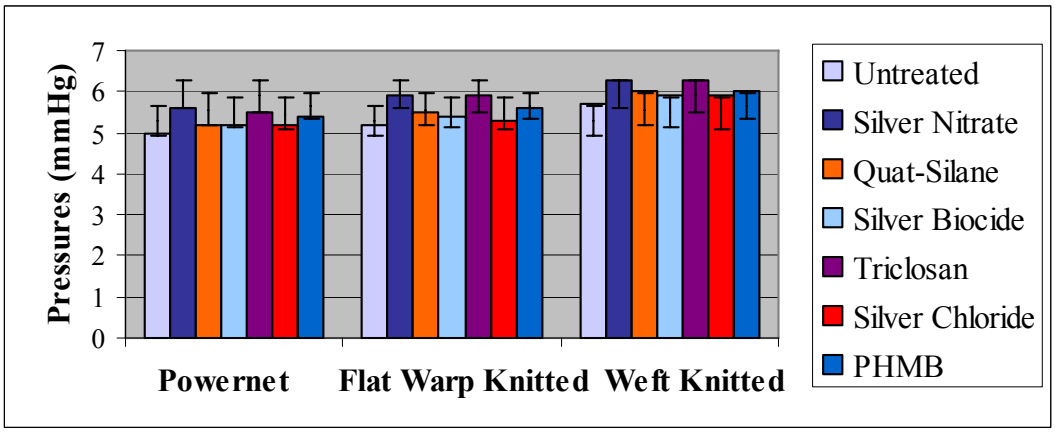


Figure 4.8: A comparison of final pressures (mmHg) for each antimicrobial agent procedure **(**Error bars: ± standard deviation).

Mean scores for final pressures were found between 5.2mmHg-6.3mmHg which is in the acceptable optimal medical range (0-50mmHg).

4.1.7 Effect of antimicrobial agents on final pressures

It is important to note that statistical analysis demonstrated that these mean values were not significantly different. From the analysis of variance and estimation of parameters effect summarized in Table 4.14, it was found that each antimicrobial agent procedure has a statistically significant effect on the final pressures ($p < 0.05$).

Table 4.14: One-way ANOVA and estimation of parameters from final pressures.

Source of Variation	SS	df	MS	F	P-value	F-crit
Between Groups	0.9	1	0.9	36	0.000323	5.317655
Within Groups	0.2	8	0.025			
Total	1.1	9				

4.1.8 Correlation between the pressures for control and treated samples

Final pressures were taken from control and treated samples. Regression analysis of the results showed that there was a correlation between control and treated samples with silver nitrate as the polynomial formula, $y = 0.2777x^3 + 2.9208x2+8.6386x$, $r^2 = 0.9822$ as shown in Figure 4.9. It is observable from the figure that pressures for control and treated samples were strongly correlated. Silver nitrate antimicrobial agent had a significant effect on final pressures.

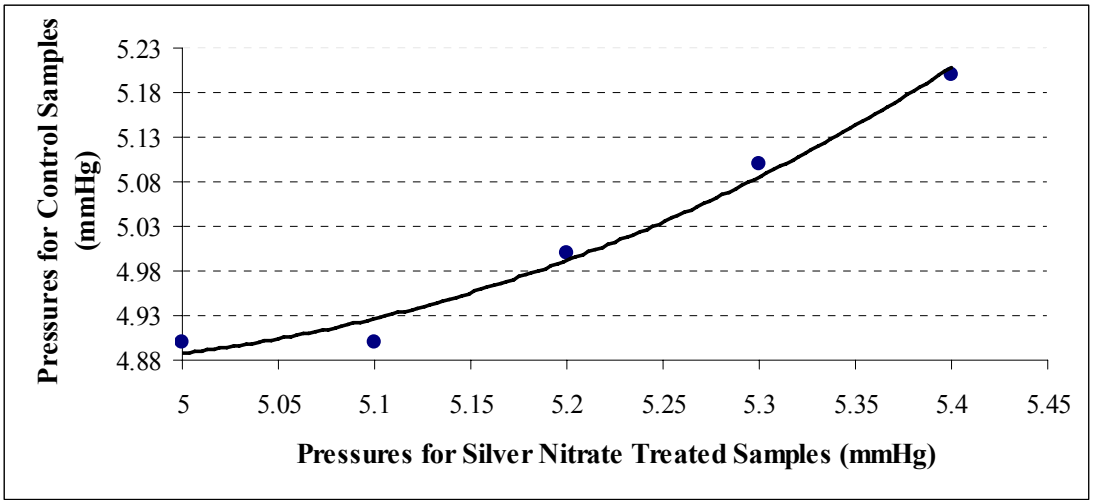


Figure 4.9: Pressures for silver nitrate treated samples from control samples.

Regression analysis of the results showed that there was a correlation between control and treated samples with quat-silane as the polynomial formula, $y = 16.667x^3 - 277.14x^2 + 1536.8x - 2837$, $r^2 = 0.9973$ as shown in Figure 4.10. It is observable from the figure that pressures for control and treated samples were strongly correlated. Quat-silane antimicrobial agent had a significant effect on final pressures.

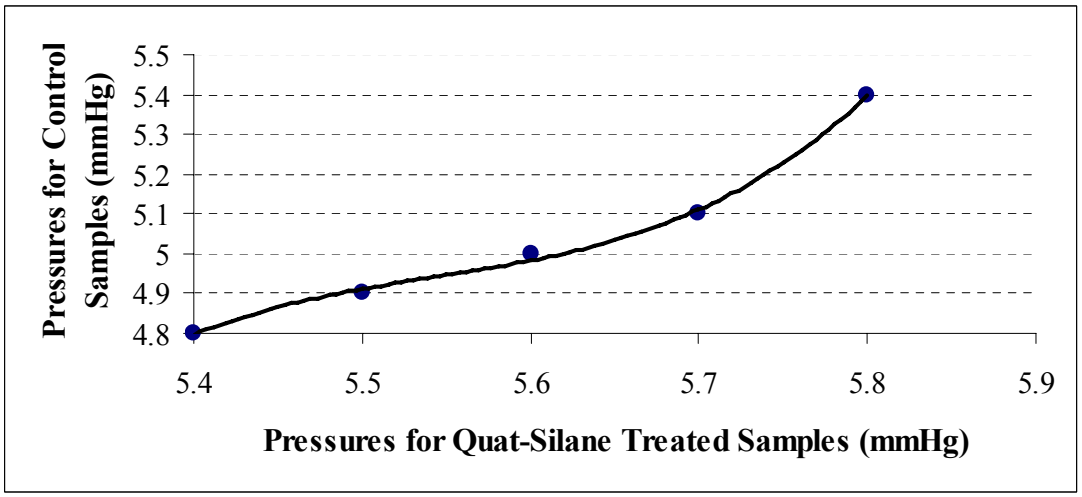


Figure 4.10: Pressures for quat-silane treated samples from control samples.

Regression analysis of the results showed that there was a correlation between control and treated samples with silver biocide as the polynomial formula, $y = 5.9748x^3 - 94.96x^2 + 503.85x - 887.33$, $r^2 = 0.9989$ as shown in Figure 4.11. It is observable from the figure that pressures for control and treated samples were strongly correlated. Silver biocide antimicrobial agent had a significant effect on final pressures.

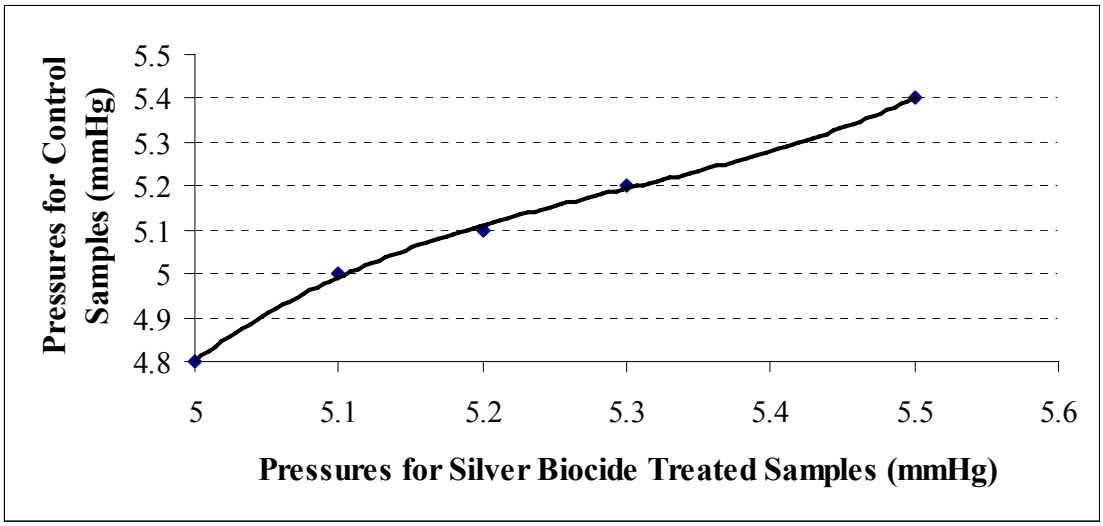


Figure 4.11: Pressures for silver biocide treated samples from control samples.

Regression analysis of the results showed that there was a correlation between control and treated samples with Triclosan as the polynomial formula, $y = 25x^3 – 411.07x^2 + 2253.8x – 4115.3$, $r^2 = 0.9995$ as shown in Figure 4.12. It is observable from the figure that pressures for control and treated samples were strongly correlated. Triclosan antimicrobial agent had a significant effect on final pressures.

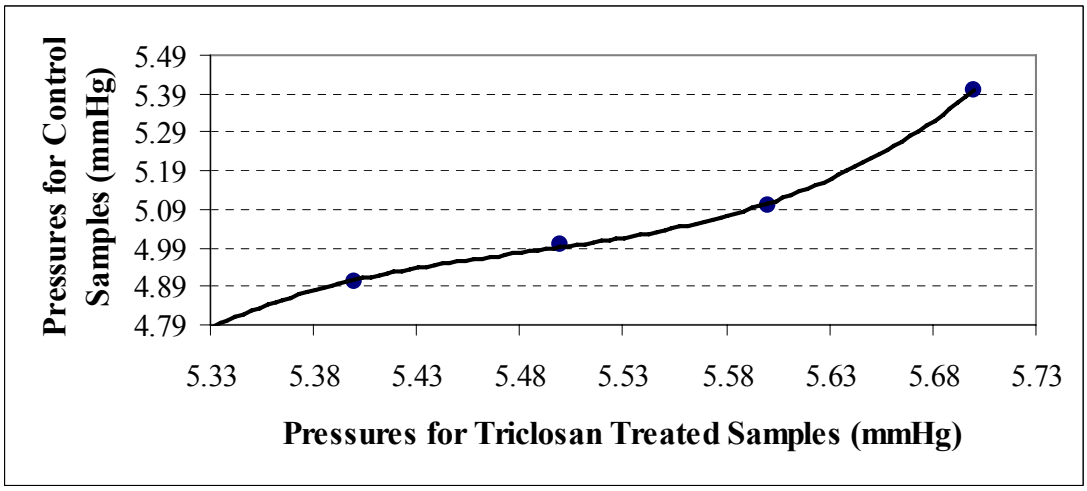


Figure 4.12: Pressures for Triclosan treated samples from control samples.

Regression analysis of the results showed that there was a correlation between control and treated samples with Triclosan as the polynomial formula, $y = 12.579x^3 – 197.36x^2 + 1032.6x – 1796.4$, $r^2 = 0.9862$ as shown in Figure 4.13. It is observable from the figure that pressures for control and treated samples were strongly correlated. Silver chloride antimicrobial agent had a significant effect on final pressures.

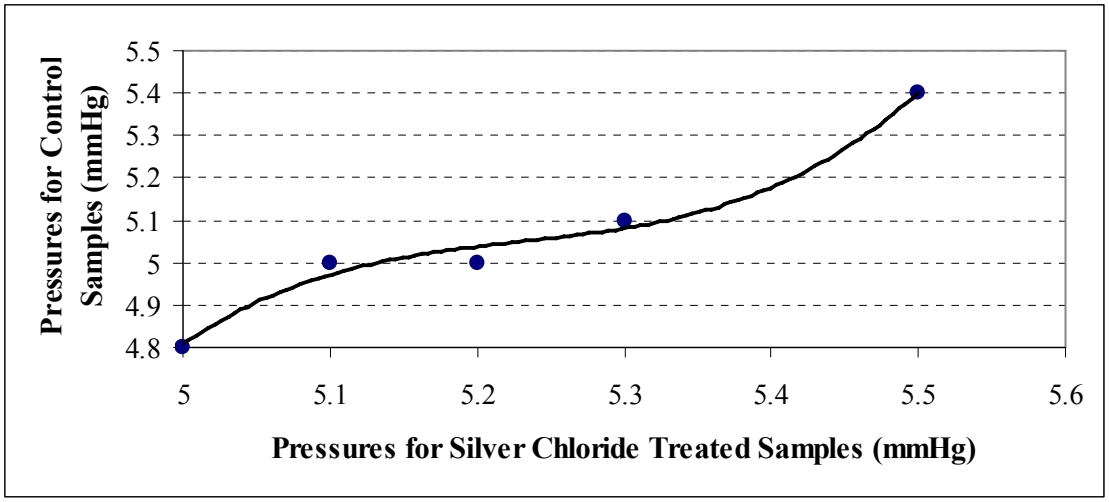


Figure 4.13: Pressures for Silver chloride treated samples from control samples.

Regression analysis of the results showed that there was a correlation between control and treated samples with PHMB as the polynomial formula, $y = 16.667x^3 – 268.57x^2 + 1443.4x – 2582.2$, $r^2 = 0.9569$ as shown in Figure 4.14. It is observable from the figure that pressures for control and treated samples were strongly correlated. PHMB antimicrobial agent had a significant effect on final pressures.

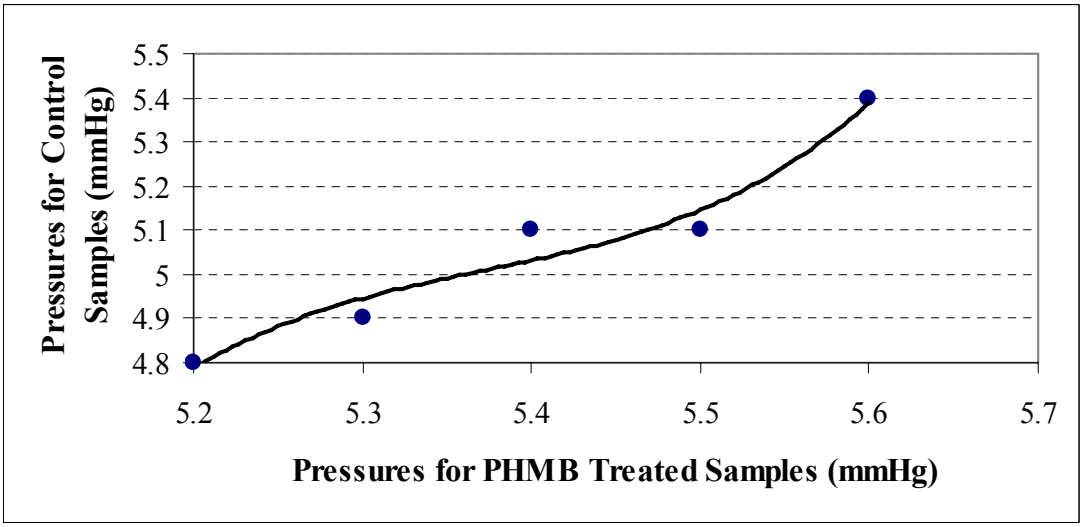


Figure 4.14: Pressures for PHMB treated samples from control samples.

4.2 Antimicrobial Activity

Untreated control samples, treated samples, also duplicate treated samples after 5, 10 and 50 washes were tested to determine antimicrobial activity following AATCC Test Method 100-2004 “Assessment of Antibacterial Finishes on Textiles” using

Staphylococcus aureus microorganism. The variables were taken as shown in Eq. (4.2).

$$R = 100\ (C-A) / C \quad \textbf{(4.2)}$$

R = % reduction

A = the number of bacteria recovered from the inoculated treated sample

C = the number of bacteria recovered from the inoculated untreated control sample

4.2.1 Silver Nitrate antimicrobial agent

The percent reduction of bacteria for fabric samples before, after treatment, plus the treated samples after 5,10 and 50 washes are shown in Tables (4.15 - 4.17). Fabric samples exhibited strong bactericidal activity after treatment. Excellent results were found for powernet fabric samples. The results can be evaluated as very good for flat warp and weft knitted fabric samples. Strong antibacterial activities remained the same for fabric samples even after 5 washes while a small significant decrease was observed after 10 and 50 washes. A comparison of antimicrobial activity for fabrics treated with silver nitrate antimicrobial agent procedure can be seen in Figure 4.15.

Table 4.15: Percentage reduction of bacteria (R) for untreated and treated powernet warp knitted fabric samples with silver nitrate antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Powernet warp knitted	00.00	> 99.99	> 99.99	99.97	96.93

Table 4.16: Percentage reduction of bacteria (R) for untreated and treated flat warp knitted fabric samples with silver nitrate antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Flat warp knitted	00.00	99.98	99.98	99.93	96.80

Table 4.17: Percentage reduction of bacteria (R) for untreated and treated weft knitted fabric samples with silver nitrate antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Weft knitted	00.00	99.96	99.96	99.90	96.75

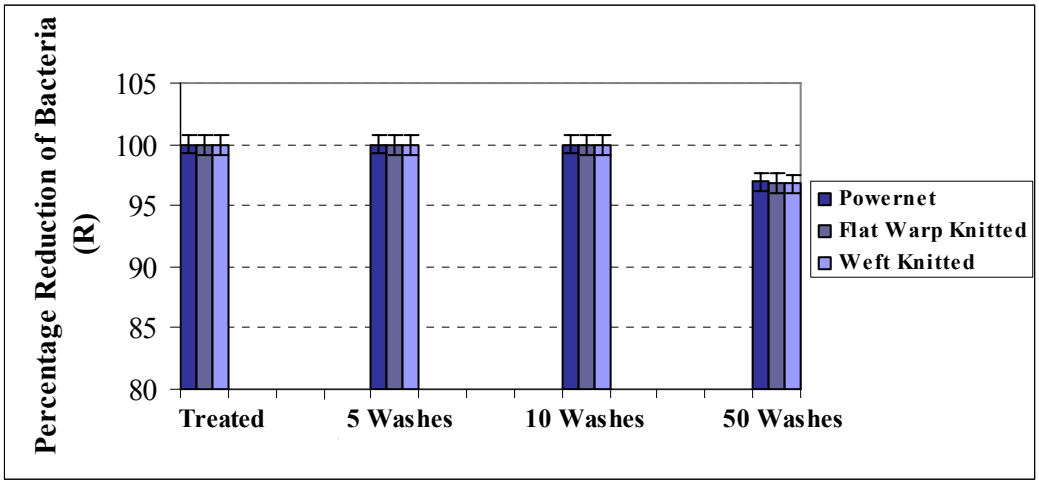


Figure 4.15: A comparison of antimicrobial activity for silver nitrate antimicrobial agent procedure in terms of fabric structure.

4.2.2 Quat-Silane antimicrobial agent

The percentage reduction of bacteria for treated samples with Quat-Silane antimicrobial agent are shown in Tables (4.18 - 4.20). Treated fabric samples showed a very good antimicrobial activity. The results were preserved also after 5 washes. A small significant decrease was observed for fabric samples after 10 and 50 washes and the antimicrobial activity was observed as very good for fabric samples after 10 and 50 washes. A comparison of antimicrobial activity for fabrics treated with Quat-Silane antimicrobial agent procedure can be seen in Figure 4.16.

Table 4.18: Percentage reduction of bacteria (R) for untreated and treated powernet warp knitted fabric samples with Quat-Silane antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Powernet warp knitted	00.00	99.70	99.70	99.65	89.50

Table 4.19: Percentage reduction of bacteria (R) for untreated and treated flat warp knitted samples with Quat-Silane antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Flat warp knitted	00.00	99.68	99.68	98.62	89.30

Table 4.20: Percentage reduction of bacteria (R) for untreated and treated weft knitted samples with Quat-Silane antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Weft knitted	00.00	99.66	99.66	98.61	88.66

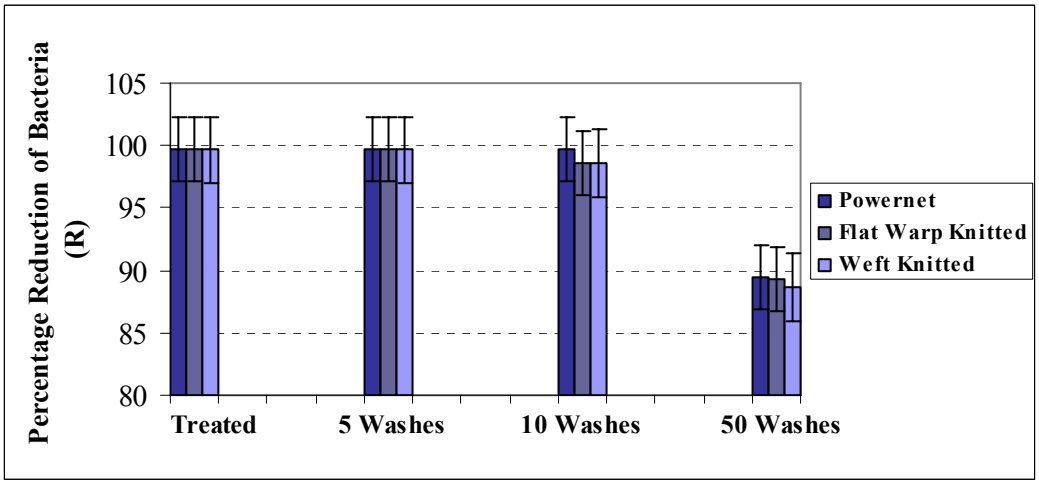


Figure 4.16: A comparison of antimicrobial activity for Quat-Silane antimicrobial agent procedure in terms of fabric structure.

4.2.3 Silver Biocide antimicrobial agent

The percentage reduction of bacteria for treated samples with silver biocide antimicrobial agent are shown in Tables (4.21 - 4.23). All treated samples showed a very good antimicrobial activity. The antimicrobial activity remained constant after 5 washes for fabric samples. Fabric samples showed a small significant decrease after 10 and 50 washes. A comparison of antimicrobial activity for fabrics treated with silver biocide antimicrobial agent procedure can be seen in Figure 4.17.

Table 4.21: Percentage reduction of bacteria (R) for untreated and treated powernet warp knitted fabric samples with silver embedded in titanium dioxide crystal antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Powernet warp knitted	00.00	99.96	99.96	98.85	83.75

Table 4.22: Percentage reduction of bacteria (R) for untreated and treated flat warp knitted fabric samples with silver embedded in titanium dioxide crystal antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Flat warp knitted	00.00	99.85	99.84	98.80	82.50

Table 4.23: Percentage reduction of bacteria (R) for untreated and treated weft knitted fabric samples with silver embedded in titanium dioxide crystal antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Weft knitted	00.00	99.78	99.77	97.99	80.00

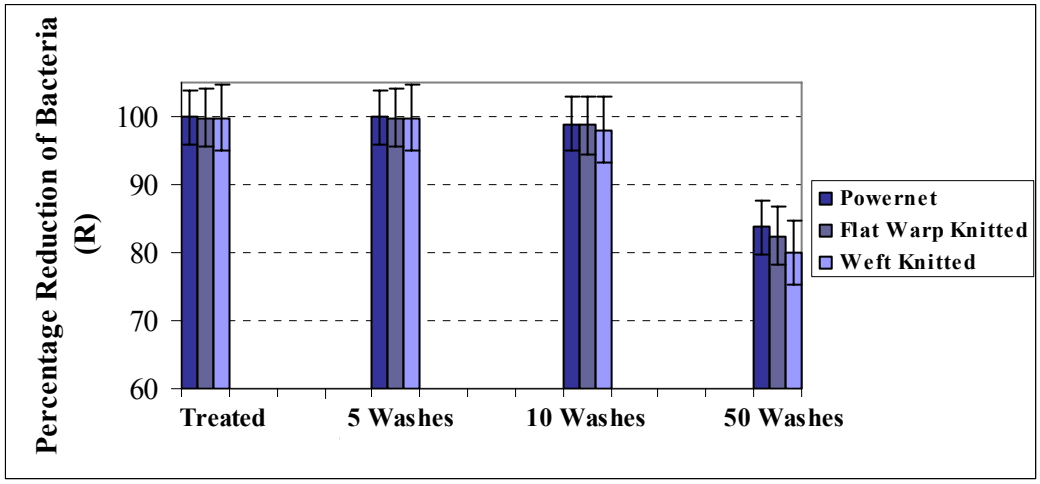


Figure 4.17: A comparison of antimicrobial activity for silver embedded in titanium dioxide crystal antimicrobial agent procedure in terms of fabric structure.

4.2.4 Triclosan antimicrobial agent

The percentage reduction of bacteria for treated samples with Triclosan antimicrobial agent are shown in Tables (4.24 - 4.26). Antimicrobial activity was very good for all fabric samples. The antimicrobial activity was preserved after 5 washes for all fabric samples. The antimicrobial activity was observed as very good even after 10 washes and a small significant decrease was observed after 50 washes and the antimicrobial activity was evaluated as good for fabric samples. A comparison of antimicrobial activity for fabrics treated with Triclosan antimicrobial agent procedure can be seen in Figure 4.18.

Table 4.24: Percentage reduction of bacteria (R) for untreated and treated powernet warp knitted fabric samples with Triclosan antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Powernet warp knitted	00.00	98.51	98.51	98.46	89.14

Table 4.25: Percentage reduction of bacteria (R) for untreated and treated flat warp knitted fabric samples with Triclosan antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Flat warp knitted	00.00	98.33	98.33	98.40	88.33

Table 4.26: Percentage reduction of bacteria (R) for untreated and treated weft knitted fabric samples with Triclosan antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Weft knitted	00.00	98.30	98.30	98.38	84.50

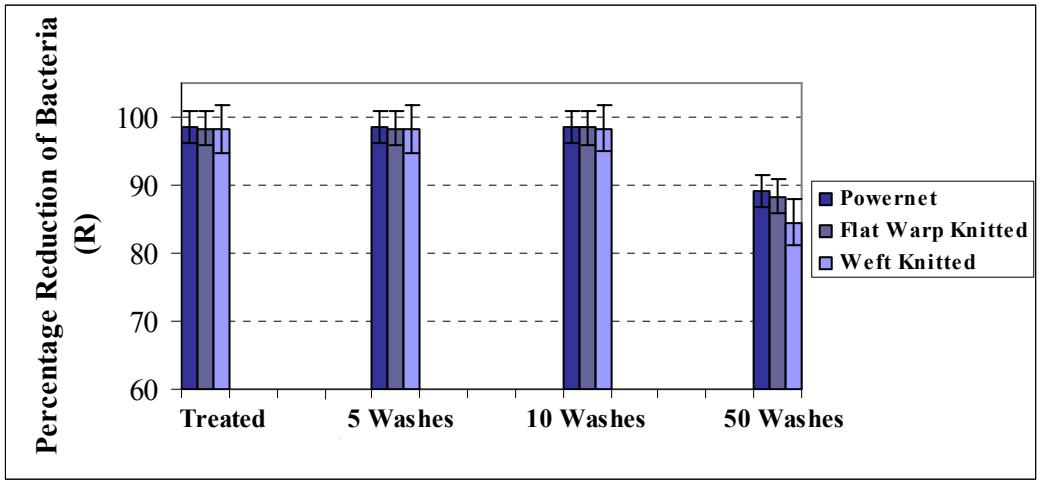


Figure 4.18: A comparison of antimicrobial activity for Triclosan antimicrobial agent procedure in terms of fabric structure.

4.2.5 Silver Chloride antimicrobial agent

The percentage reduction of bacteria for treated samples with silver chloride antimicrobial agent are shown in Tables (4.27 – 4.29). Excellent antimicrobial activity was observed for powernet fabric samples. Excellent antimicrobial activity for powernet fabric samples was preserved also after 5 washes. The antimicrobial activity was observed as very good for flat warp and weft knitted fabric samples. A small significant decrease was observed for fabric samples after 10 and 50 washes and the antimicrobial activity was evaluated as good for all fabric samples. A comparison of antimicrobial activity for fabrics treated with silver chloride antimicrobial agent procedure can be seen in Figure 4.19.

Table 4.27: Percentage reduction of bacteria (R) for untreated and treated powernet warp knitted fabric samples with silver chloride antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Powernet warp knitted	00.00	> 99.99	> 99.99	99.93	89.90

Table 4.28: Percentage reduction of bacteria (R) for untreated and treated flat warp knitted fabric samples with silver chloride antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Flat warp knitted	00.00	99.90	99.90	98.84	89.78

Table 4.29: Percentage reduction of bacteria (R) for untreated and treated weft knitted fabric samples with silver chloride antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Weft knitted	00.00	99.88	99.88	98.82	88.74

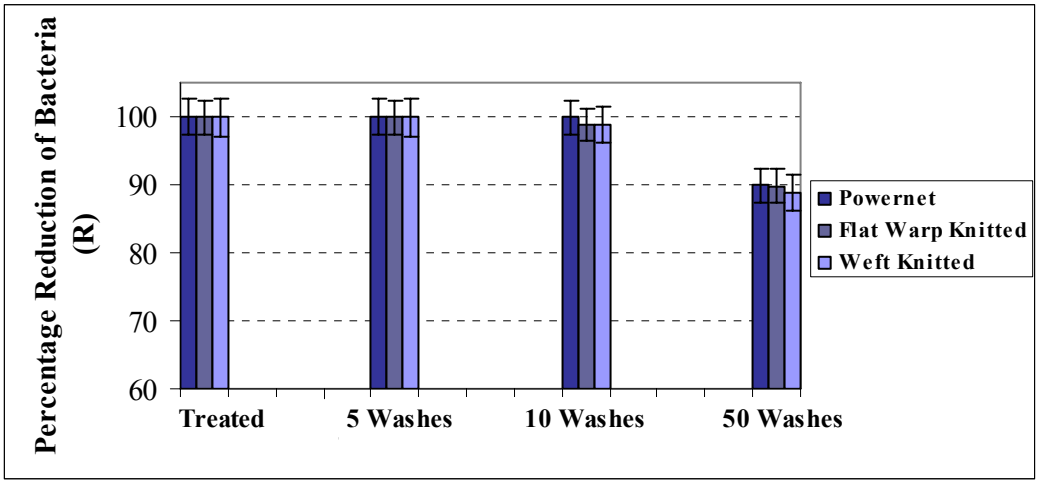


Figure 4.19: A comparison of antimicrobial activity for silver chloride antimicrobial agent procedure in terms of fabric structure.

4.2.6 PHMB antimicrobial agent

The percentage reduction of bacteria for treated samples with PHMB antimicrobial agent are shown in Tables (4.30 – 4.32). PHMB treated samples showed excellent antimicrobial activity for all fabric samples. The antimicrobial activity for each fabric sample was preserved even after 5 washes. After 10 and 50 washes a very good antimicrobial activity was observed with a small significant decrease for fabric samples. A comparison of antimicrobial activity for fabrics treated with PHMB antimicrobial agent procedure can be seen in Figure 4.20.

Table 4.30: Percentage reduction of bacteria (R) for untreated and treated powernet warp knitted fabric samples with PHMB antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Powernet warp knitted	00.00	> 99.99	> 99.99	99.97	96.90

Table 4.31: Percentage reduction of bacteria (R) for untreated and treated flat warp knitted fabric samples with PHMB antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Flat warp knitted	00.00	> 99.99	> 99.99	99.95	96.85

Table 4.32: Percentage reduction of bacteria (R) for untreated and treated weft knitted fabric samples with PHMB antimicrobial agent.

Fabric samples	Control	Treated	5 washes	10 washes	50 washes
Weft knitted	00.00	> 99.99	> 99.99	99.92	95.98

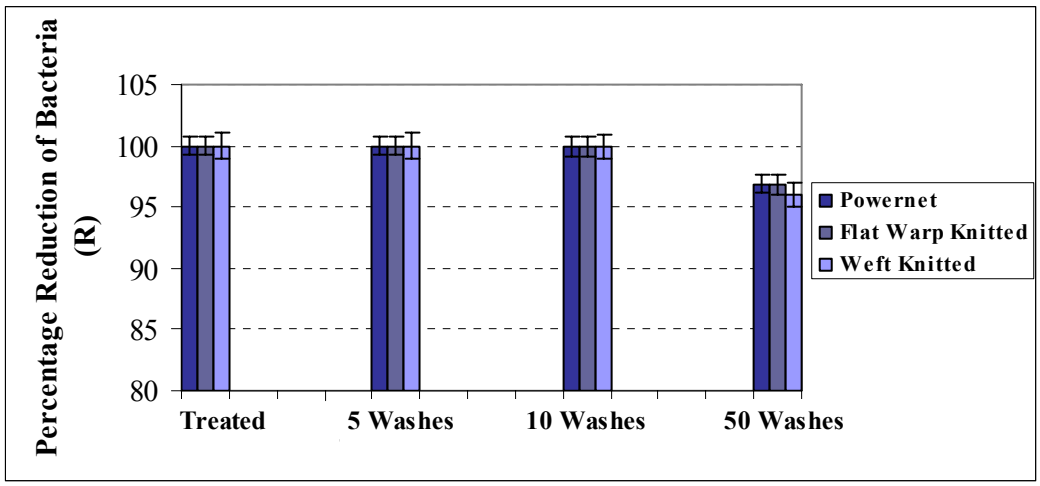


Figure 4.20: A comparison of antimicrobial activity for PHMB antimicrobial agent procedure in terms of fabric structure.

4.2.6.1 Effect of wash cycles on antimicrobial activity

ANOVA two-way with replication was used to see the effect of wash cycles on antimicrobial activity (Table 4.33). Using two-way analysis of variance, interaction was found as 0.0001. It was resulted that there is an interaction between the types of antimicrobial agents and wash cycles on antimicrobial activity (Interaction < 0.05).

Table 4.33: ANOVA and estimation of parameters from antimicrobial activity.

ANOVA two-way with replication						
Source of Variance	**SS**	**df**	**MS**	**F**	**P-value**	**F-crit**
Antimicrobial Activity	226.8333	5	45.3666	7.4236	7.1618	2.4771
Wash Cycles	592.3333	2	296.1666	48.4636	6.1432	3.2594
Interaction	319.6666	10	31.9666	5.2309	**0.0001**	2.1060
Within	220	36	6.1111			
Total	1358.8333	53				

4.3 X-Ray Photoelectron Spectroscopy (XPS) Analysis

Treated samples were analyzed using XPS analysis. Control samples were used for a comparison. Carbon (C), Nitrogen (N), Oxygen (O), Fluorine (F) were detected in 1s orbit, and Silicium (Si) was detected in 2p orbit for both untreated and treated samples. Silver was detected on the surface of the treated samples in 3d orbit. The result of the analysis including atomic concentration and binding energy (eV) were shown for each treated sample with silver compound in Tables (4.34 – 4.42).

Table 4.34: Relative chemical composition and binding energy determined by XPS for powernet warp knitted fabric samples treated with silver nitrate antimicrobial chemical agent.

	Control Sample				**Treated Sample**			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	62.44
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.53
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	2.67
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.52
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.20

Pos: Binding energy in eV, **FWHM:** Full with half maximum (High Energy Resolution), **Area:** Area under the curve (cm^2), **At%:** Atomic percent

Table 4.35: Relative chemical composition and binding energy determined by XPS for powernet warp knitted fabric samples treated with silver embedded in titanium dioxide crystal antimicrobial chemical agent.

Control Sample					Treated Sample			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	63.10
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.00
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	3.00
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.50
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.20

Table 4.36: Relative chemical composition and binding energy determined by XPS for powernet warp knitted fabric samples treated with silver chloride antimicrobial chemical agent.

Control Sample					Treated Sample			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	63.10
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.00
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	3.00
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.50
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.20

Table 4.37: Relative chemical composition and binding energy determined by XPS for flat warp knitted fabric samples treated with silver nitrate antimicrobial chemical agent.

Control Sample					Treated Sample			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	63.10
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.00
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	3.00
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.50
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.18

Table 4.38: Relative chemical composition and binding energy determined by XPS for flat warp knitted fabric samples treated with silver embedded in titanium dioxide crystal antimicrobial chemical agent.

Control Sample					Treated Sample			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	63.10
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.00
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	3.00
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.50
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.18

Table 4.39: Relative chemical composition and binding energy determined by XPS for flat warp knitted fabric samples treated with silver chloride antimicrobial chemical agent.

Control Sample					Treated Sample			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	63.10
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.00
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	3.00
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.50
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.18

Table 4.40: Relative chemical composition and binding energy determined by XPS for weft knitted fabric samples treated with silver nitrate antimicrobial chemical agent.

Control Sample					Treated Sample			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	63.10
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.00
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	3.00
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.50
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.16

Table 4.41: Relative chemical composition and binding energy determined by XPS for weft knitted fabric samples treated with silver embedded in titanium dioxide crystal antimicrobial chemical agent.

Control Sample					Treated Sample			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	63.10
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.00
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	3.00
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.50
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.16

Table 4.42: Relative chemical composition and binding energy determined by XPS for weft knitted fabric samples treated with silver chloride antimicrobial chemical agent.

Control Sample					Treated Sample			
Name	**Pos.**	**FWHM**	**Area**	**At%**	**Pos.**	**FWHM**	**Area**	**At%**
C 1s	285.00	2.34	9119.10	59.85	284.50	2.55	11702.90	63.10
N 1s	400.00	2.18	960.70	3.56	399.50	2.15	886.30	23.00
O 1s	532.50	2.62	10901.00	25.10	532.00	2.61	12571.10	3.00
F 1s	690.50	2.19	1551.40	2.39	689.50	2.29	2905.50	3.64
Si 2p	102.00	1.78	1199.5	9.10	101.50	2.24	1219.90	7.50
Ag 3d	-	-	-	-	368.50	0.63	648.00	0.16

The percentage atomic concentrations of silver (Ag) were detected as 0.20% for powernet, 0.18% for flat warp knitted and 0.16% for weft knitted fabric samples for all antimicrobial treatments. This is a good result in terms of the attachment of silver antimicrobial chemical to the structure of nylon 6.6/spandex fabrics and shows that the amount of silver antimicrobial chemical is bonded successfully to the structure.

4.4 Scanning Electron Microscopy (SEM) Analysis

Scanning electron microscopy (SEM) analysis were performed on three different sample sets to see if the antimicrobial chemical solution appeared on the fabric and fiber surfaces.

4.4.1 SEM analysis for untreated samples

SEM images for the untreated samples were obtained to make a comparison Figures (4.21- 4.23).

Figure 4.21: SEM Images for untreated powernet warp knitted fabric samples (Magnification X1100).

Figure 4.22: SEM images for untreated flat warp knitted fabric samples; (Magnification X1100).

Figure 4.23: SEM images for untreated weft knitted fabric samples; (Magnification X1140).

4.4.2 SEM analysis for treated samples

SEM images of the treated samples are shown in Figures (4.24 - 4.41).

4.4.2.1 Silver Nitrate antimicrobial agent

SEM analysis revealed that on the silver nitrate antimicrobial treated Nylon 6.6 / Spandex, the fibers showed more compact and more aligned appearance for all fabric samples when compared with that of the control. It appears from SEM images that the bonded chemical in the structure still exists after 5, 10 and 50 washes. The observation of the chemical itself on the surface of the fibers and in between the fibers by forming a triangle region, support the idea about the bonding of the antimicrobial chemical to the structure of the fabrics and the strength of the attachments even after 5, 10 and 50 washes after treatments. SEM photomicrographs for treated fabric samples with silver nitrate are presented in Figures (4.24 - 4.26).

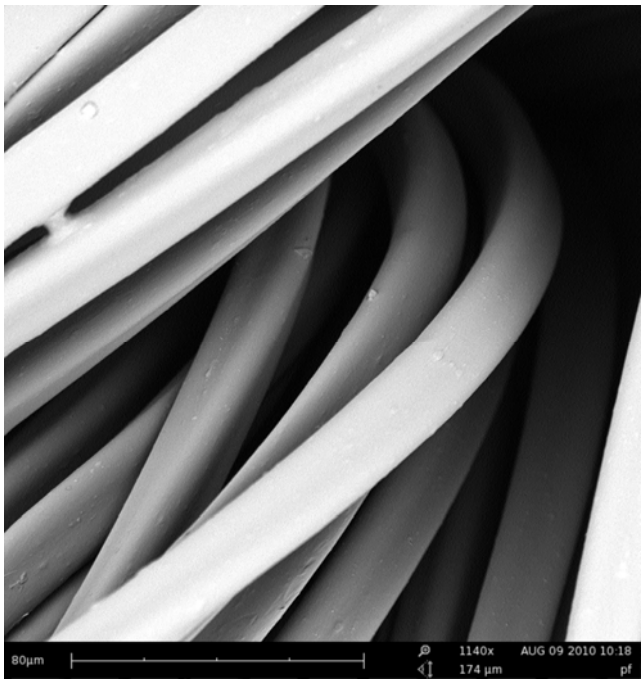


Figure 4.24: SEM images for treated powernet warp knitted samples with silver nitrate antimicrobial agent; (Magnification X1140).

Figure 4.25: SEM images for treated flat warp knitted samples with silver nitrate antimicrobial agent; (Magnification X1000).

Figure 4.26: SEM images for treated weft knitted fabric samples with silver nitrate antimicrobial agent; (Magnification X1000).

4.4.2.2 Quat-Silane antimicrobial agent

Antimicrobial solution appeared on the surface of the fabrics and in the fibers for all fabric samples treated with quat-silane antimicrobial chemical. SEM images for treated samples with quat-silane are shown in Figures (4.27 – 4.29). Fibers aligned and bright structure and the bonding of the fibers through the length of the fibers and the bonding from one point strongly confirm the antimicrobial treatments were successful for each fabric sample.

Figure 4.27: SEM images for treated powernet warp knitted fabric samples with Quat Silane antimicrobial agent; (Magnification X1100).

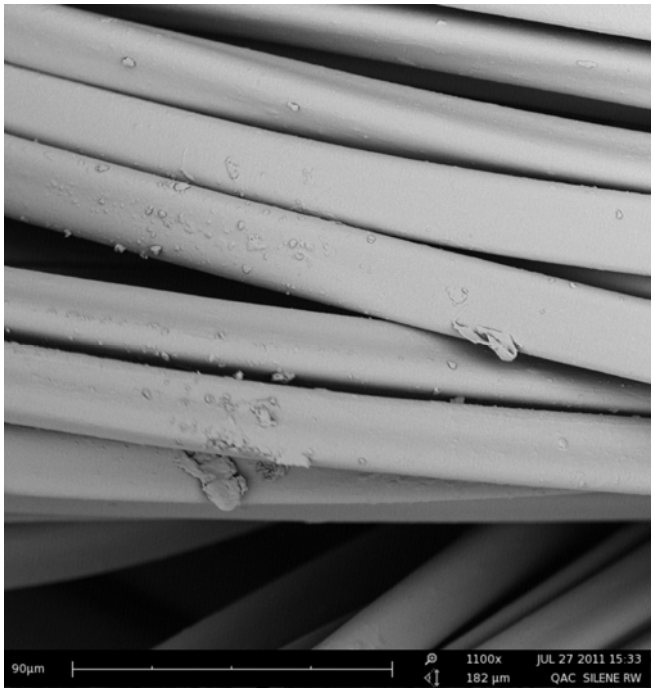


Figure 4.28: SEM images for treated flat warp knitted fabric samples with Quat Silane antimicrobial agent; (Magnification X1100).

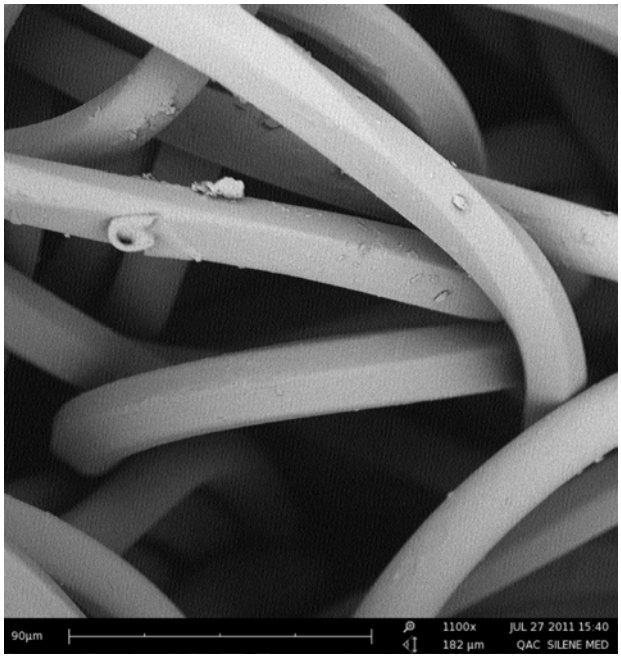


Figure 4.29: SEM images for treated weft knitted fabric samples with Quat Silane antimicrobial agent; (Magnification X1100).

4.4.2.3 Silver Biocide antimicrobial agent

Antimicrobial solution can easily be seen on the surface of the fibers and also the fiber bonding and compact structure strongly confirm the treatment was successful

for all fabric samples treated with silver embedded in titanium dioxide crystal. SEM images of fabric samples are shown in Figures (4.30 – 4.32).

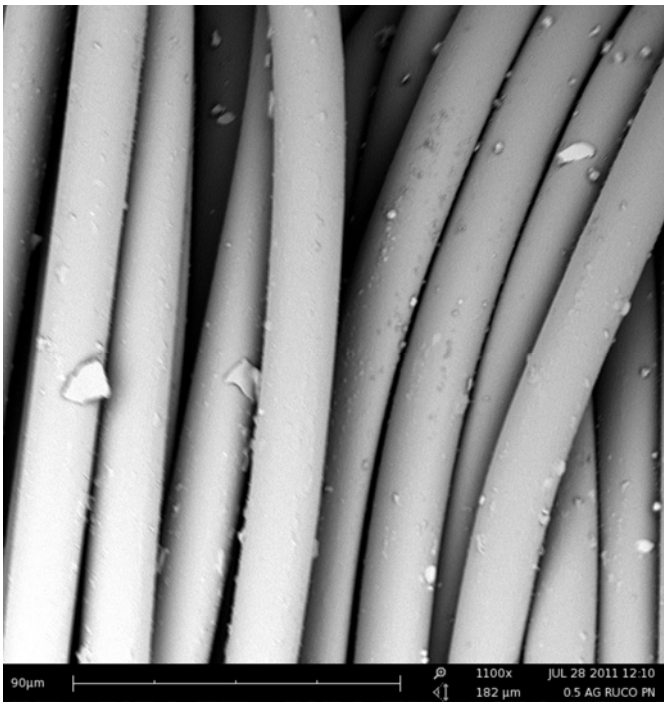


Figure 4.30: SEM images for treated powernet warp knitted fabric samples with silver biocide antimicrobial agent; (Magnification X1100).

Figure 4.31: SEM images for treated flat warp knitted fabric samples with silver biocide antimicrobial agent; (Magnification X1100).

Figure 4.32: SEM images for treated weft knitted fabric samples with silver biocide antimicrobial agent; (Magnification X1100).

4.4.2.4 Triclosan antimicrobial agent

SEM images of fabric samples treated with Triclosan antimicrobial chemical agent are shown in Figures (4.33 - 4.35).

Figure 4.33: SEM images for treated powernet warp knitted fabric samples with Triclosan antimicrobial agent; (Magnification X1100).

Figure 4.34: SEM images for treated flat warp knitted fabric samples with Triclosan antimicrobial agent; (Magnification X1100).

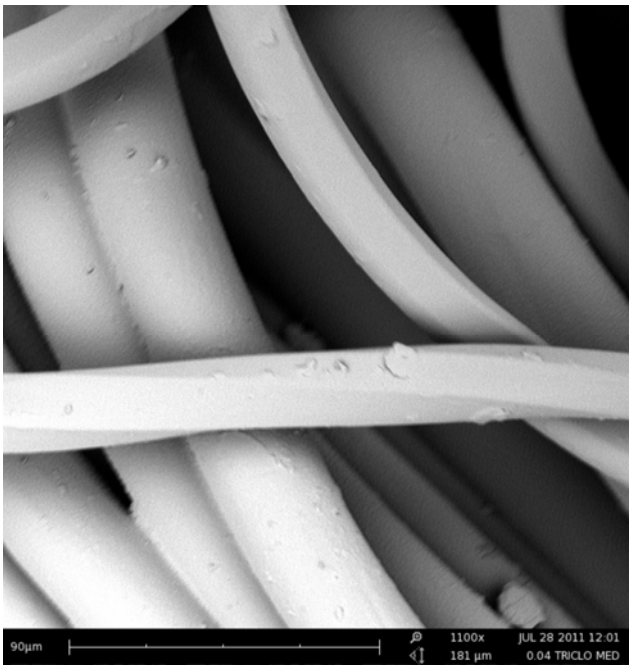


Figure 4.35: SEM images for treated weft knitted fabric samples with Triclosan antimicrobial agent; (Magnification X1100).

The bonding of the fibers, compact structure and alignment of the fibers strongly confirm the antimicrobial treatment with Triclosan antimicrobial agents was achieved.

4.4.2.5 Silver Chloride antimicrobial agent

The bonding of the fibers, the compact structure and alignment of the fibers strongly confirm the antimicrobial treatments with silver chloride were successful. SEM images of treated fabric samples with silver chloride are presented in Figures (4.36 – 4.38).

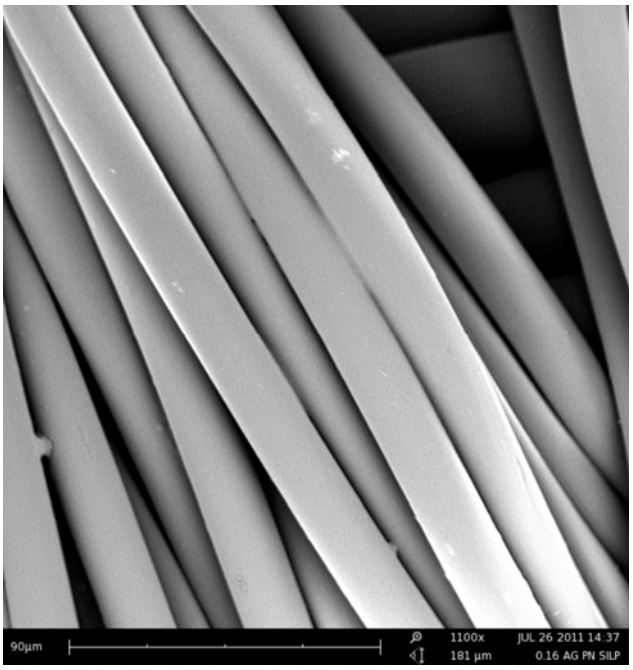


Figure 4.36: SEM images for treated powernet warp knitted fabric samples with silver chloride antimicrobial agent; (Magnification X1100).

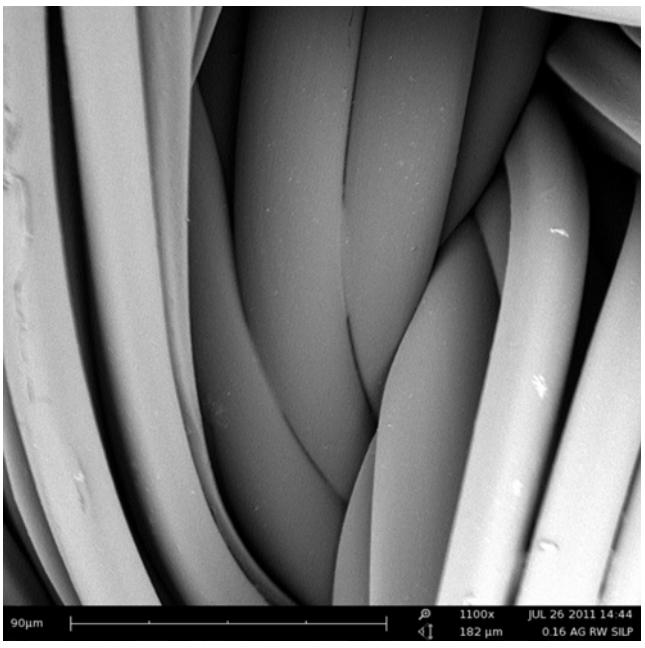


Figure 4.37: SEM images for treated flat warp knitted fabric samples with silver chloride antimicrobial agent; (Magnification X1100).

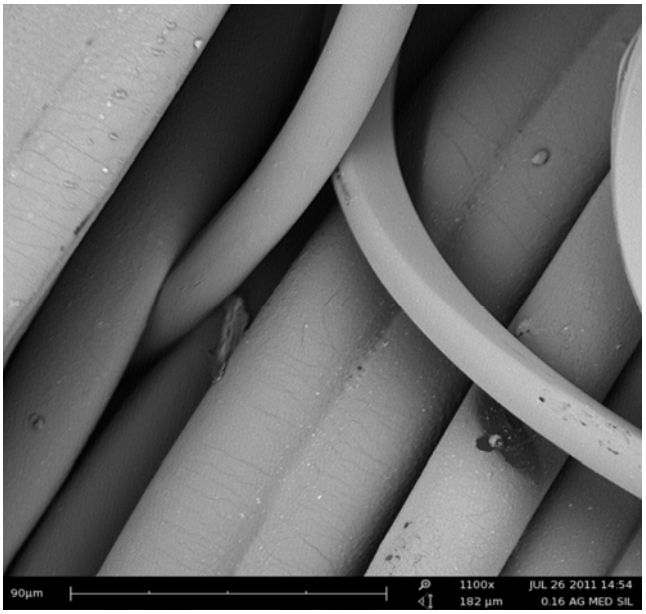


Figure 4.38: SEM images for treated weft knitted fabric samples with silver chloride antimicrobial agent; (Magnification X1100).

4.4.2.6 PHMB antimicrobial agent

The bonding of 4-8 fibers together and forming a compact and brighter structure after the treatments show that the antimicrobial treatments were successful. SEM images of treated fabric samples with PHMB antimicrobial solutions are shown in Figures (4.39 – 4.41).

Figure 4.39: SEM images for treated powernet fabric samples with PHMB antimicrobial chemical agent; (Magnification X1100).

Figure 4.40: SEM images for treated flat warp knitted fabric samples with PHMB antimicrobial chemical agent; (Magnification X1100).

Figure 4.41: SEM images for treated weft knitted fabric samples with PHMB antimicrobial chemical agent; (Magnification X1100).

4.5 Fourier Transform Infrared Spectroscopy (FTIR) Analysis

4.5.1 Silver Nitrate antimicrobial agent

In order to identify the infrared absorption spectrum and detect any changes in the structure of the silver nitrate treated samples during treatment, treated samples were scanned using a Nicolet Nexus 470 Spectrophotometer with AVATAR Omni Sampler for Attenuated Total Reflectance (ATR) mode. The aggregated scans showing the absorbance across the infrared spectrum was acquired using OMNIC™ software.

Figure 4.42 shows FTIR spectra of untreated and treated fabric samples with silver nitrate. The presence of the band at 1387 cm^{-1} indicates the presence of silver nitrate [199].

Spectral comparisons of (a) treated powernet warp knitted showed the absorption bands (1387 cm^{-1}) in the spectrum, (b) untreated powernet warp control fabric showed no absorption bands at 1387cm^{-1}, (c) treated flat warp knitted fabric showed the absorption bands (1387 cm^{-1}) in the spectrum, (d) untreated flat warp control fabric showed no absorption bands at (1387cm^{-1}), (e) treated weft knitted fabric showed the absorption bands (1387 cm^{-1}) in the spectrum, (f) untreated weft control knitted fabric samples showed no absorption bands at (1387cm^{-1}).

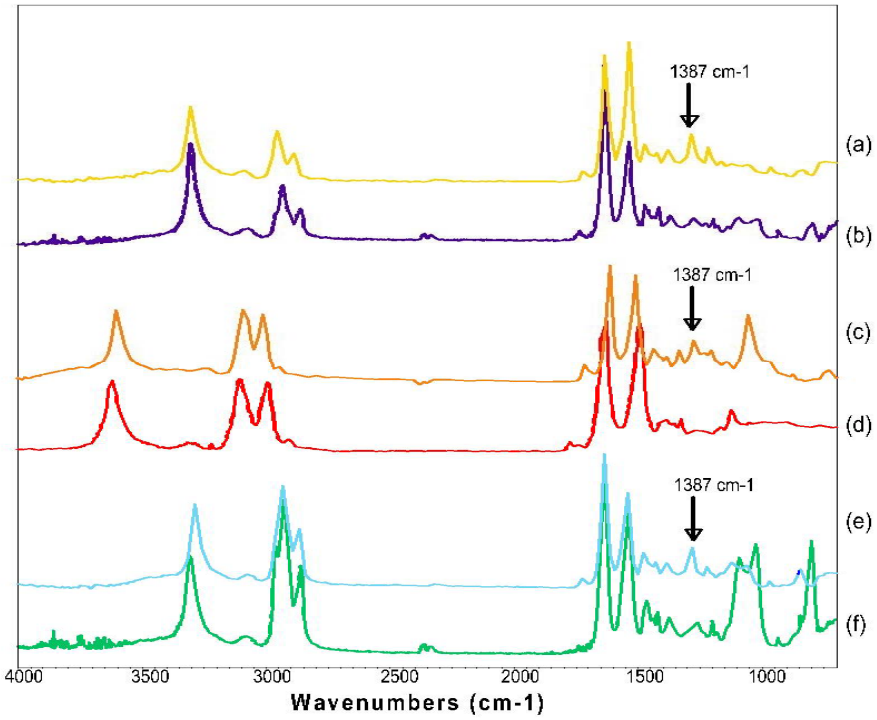


Figure 4.42: FTIR spectra of the fabric samples after treatment with silver nitrate (a) treated powernet warp, (b) untreated powernet warp control, (c) treated flat warp, (d) untreated flat warp control, (e) treated weft, (f) untreated weft control knitted fabric samples.

4.5.2 Quat - Silane antimicrobial agent

In order to identify the infrared absorption spectrum and detect any changes in the structure of the quat-silane treated samples during treatment, treated samples were scanned using a Nicolet Nexus 470 Spectrophotometer with AVATAR Omni Sampler for Attenuated Total Reflectance (ATR) mode. The aggregated scans showing the absorbance across the infrared spectrum was acquired using OMNIC™ software.

Figure 4.43 shows FTIR spectra of untreated and treated fabric samples with quat-silane. Combination bands observed in the 2000–1500 cm^{-1} region in the IR spectrum of antimicrobial quat-silane agent indicate that the compound contains the C-NH3 grouping [200]. Spectral comparisons of (a) treated powernet warp knitted showed the absorption band (1800 cm^{-1}) in the spectrum, (b) untreated powernet warp control fabric showed no absorption bands between 2000cm^{-1} and 1500cm^{-1}, (c) treated flat warp knitted fabric showed the absorption band (1780 cm^{-1}) in the spectrum, (d) untreated flat warp control fabric showed no absorption bands between 2000cm^{-1} and 1500cm^{-1}, (e) treated weft knitted fabric showed the absorption band

(1790 cm^{-1}) in the spectrum, (f) untreated weft control knitted fabric samples showed no absorption bands between 2000cm^{-1} and 1500cm^{-1}.

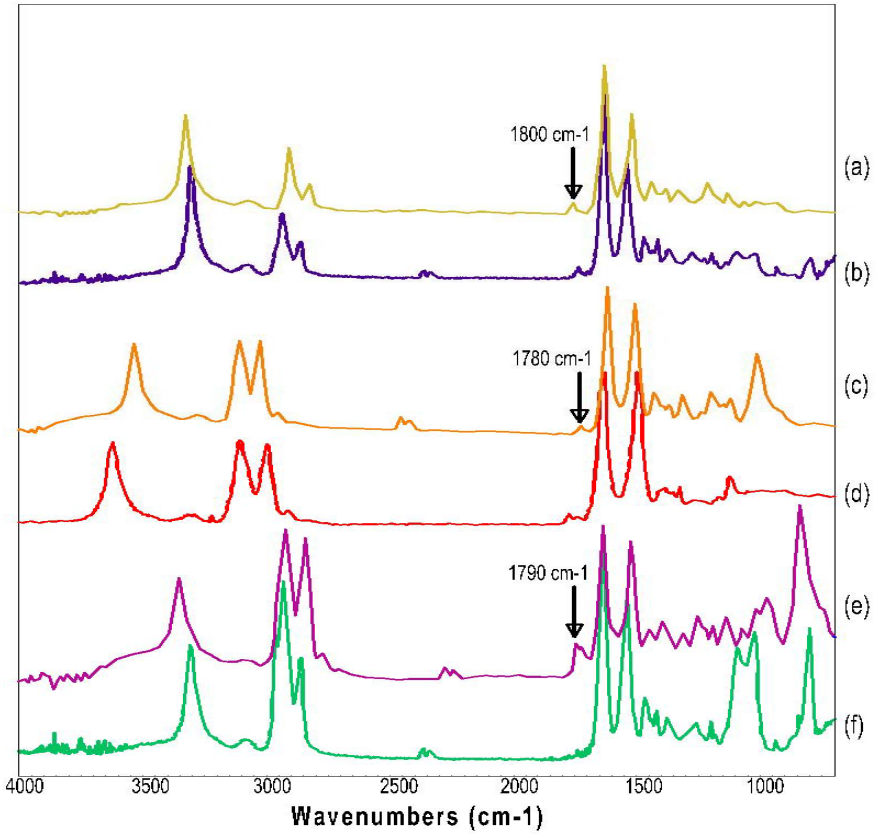


Figure 4.43: FTIR spectra of the fabric samples after treatment with Quat-Silane (a) treated powernet warp, (b) untreated powernet warp control, (c) treated flat warp, (d) untreated flat warp control, (e) treated weft, (f) untreated weft control knitted fabric samples.

4.5.3 Silver Biocide antimicrobial agent

In order to identify the infrared absorption spectrum and detect any changes in the structure of the silver biocide treated samples during treatment, treated samples were scanned using a Nicolet Nexus 470 Spectrophotometer with AVATAR Omni Sampler for Attenuated Total Reflectance (ATR) mode. The aggregated scans showing the absorbance across the infrared spectrum was acquired using OMNIC™ software.

Figure 4.44 shows FTIR spectra of untreated and treated fabric samples with silver biocide embedded in titanium dioxide crystal. The presence of the band 1200-1300 cm^{-1} indicates the presence of silver chloride (AgCl) [201]. As the presence of band at 768 cm^{-1} indicates the presence of titanium dioxide (TiO_2), silver was considered for the analysis [202]. Micro-structured TiO_2 is the carrier of the active component.

Spectral comparisons of (a) treated powernet warp knitted showed the absorption bands (768 cm^{-1} and 1250 cm^{-1}) in the spectrum, (b) untreated powernet warp control fabric showed no absorption bands between 1200cm^{-1} and 1300cm^{-1}, (c) treated flat warp knitted fabric showed the absorption bands (768 cm^{-1} and 1240 cm^{-1}) in the spectrum, (d) untreated flat warp control fabric showed no absorption bands between 1200cm^{-1} and 1300cm^{-1}, (e) treated weft knitted fabric showed the absorption bands (768 cm^{-1} and 1250 cm^{-1}) in the spectrum, (f) untreated weft control knitted fabric samples showed no absorption bands between 1200cm^{-1} and 1300cm^{-1}.

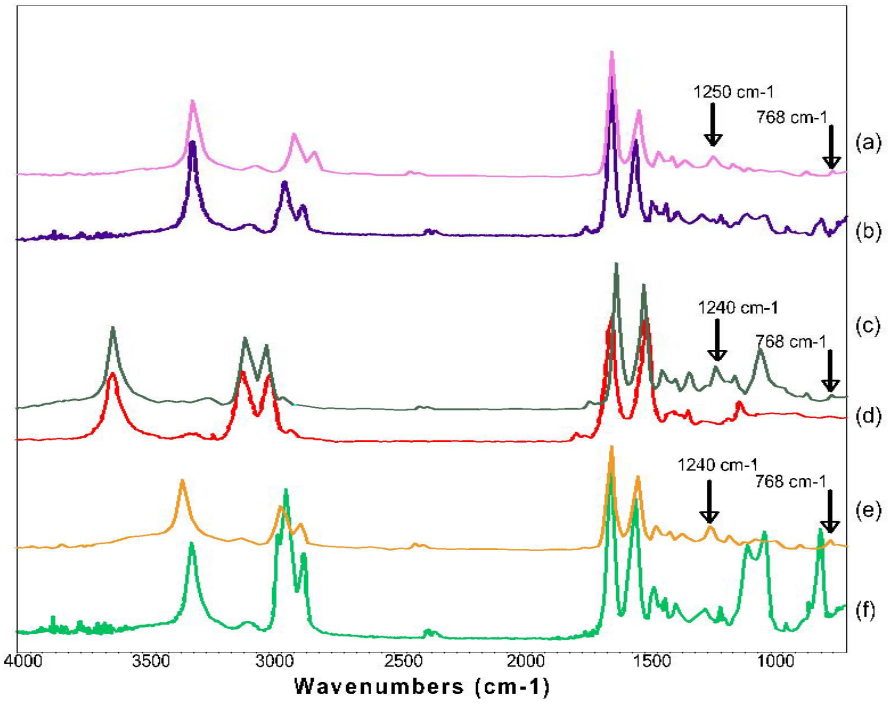


Figure 4.44: FTIR spectra of the fabric samples after treatment with silver biocide embedded in titanium dioxide crystal (a) treated powernet warp, (b) untreated powernet warp control, (c) treated flat warp, (d) untreated flat warp control, (e) treated weft, (f) untreated weft control knitted fabric samples.

4.5.4 Triclosan antimicrobial agent

In order to identify the infrared absorption spectrum and detect any changes in the structure of the Triclosan treated samples during treatment, treated samples were scanned using a Nicolet Nexus 470 Spectrophotometer with AVATAR Omni Sampler for Attenuated Total Reflectance (ATR) mode. The aggregated scans showing the absorbance across the infrared spectrum was acquired using OMNIC™ software.

Figure 4.45 shows FTIR spectra of untreated and treated fabric samples with Triclosan. The spectrum search in the FTIR has confirmed that the sample shows the presence of the antimicrobial agent Triclosan, as indicated by the peak for antimicrobial Triclosan at wave number 1445 cm^{-1}, where the reference peak C-O= at wave number 1475cm^{-1} [203].

Spectral comparisons of (a) treated powernet warp knitted showed the absorption bands (1445 cm^{-1} and 1475 cm^{-1}) in the spectrum, (b) untreated powernet warp control fabric showed no absorption bands at 1445cm^{-1} and 1475cm^{-1}, (c) treated flat warp knitted fabric showed the absorption bands (1445 cm^{-1} and 1475 cm^{-1}) in the spectrum, (d) untreated flat warp control fabric showed no absorption bands at 1445cm^{-1} and 1475cm^{-1}, (e) treated weft knitted fabric showed the absorption bands at 1445cm^{-1} and 1475cm^{-1} in the spectrum, (f) untreated weft control knitted fabric samples showed no absorption bands at 1445cm^{-1} and 1475cm^{-1} .

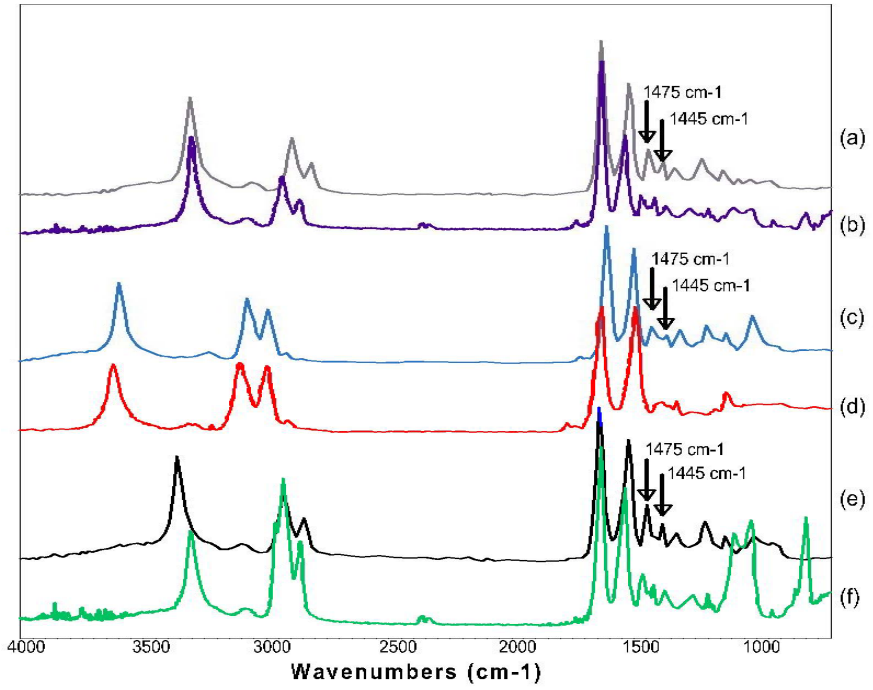


Figure 4.45: FTIR spectra of the fabric samples after treatment with Triclosan (a) treated powernet warp, (b) untreated powernet warp control, (c) treated flat warp, (d) untreated flat warp control, (e) treated weft, (f)untreated weft control knitted fabric samples.

4.5.5 Silver Chloride antimicrobial agent

In order to identify the infrared absorption spectrum and detect any changes in the structure of the silver chloride treated samples during treatment, treated samples

were scanned using a Nicolet Nexus 470 Spectrophotometer with AVATAR Omni Sampler for Attenuated Total Reflectance (ATR) mode. The aggregated scans showing the absorbance across the infrared spectrum was acquired using OMNIC™ software.

Figure 4.46 shows FTIR spectra of untreated and treated fabric samples with silver chloride. The presence of the band 1200-1300 cm^{-1} indicates the presence of silver chloride (AgCl) [201]. Spectral comparisons of (a) treated powernet warp knitted showed the absorption bands (1223 cm^{-1}) in the spectrum, (b) untreated powernet warp control fabric showed no absorption bands between 1200cm^{-1} and 1300cm^{-1}, (c) treated flat warp knitted fabric showed the absorption bands (1230 cm^{-1}) in the spectrum, (d) untreated flat warp control fabric showed no absorption bands between 1200cm^{-1} and 1300cm^{-1}, (e) treated weft knitted fabric showed the absorption bands (1205 cm^{-1}) in the spectrum, (f) untreated weft control knitted fabric samples showed no absorption bands between 1200cm^{-1} and 1300cm^{-1}. The presence of the band between 1200 -1300 cm^{-1} indicates the presence of silver chloride (AgCl).

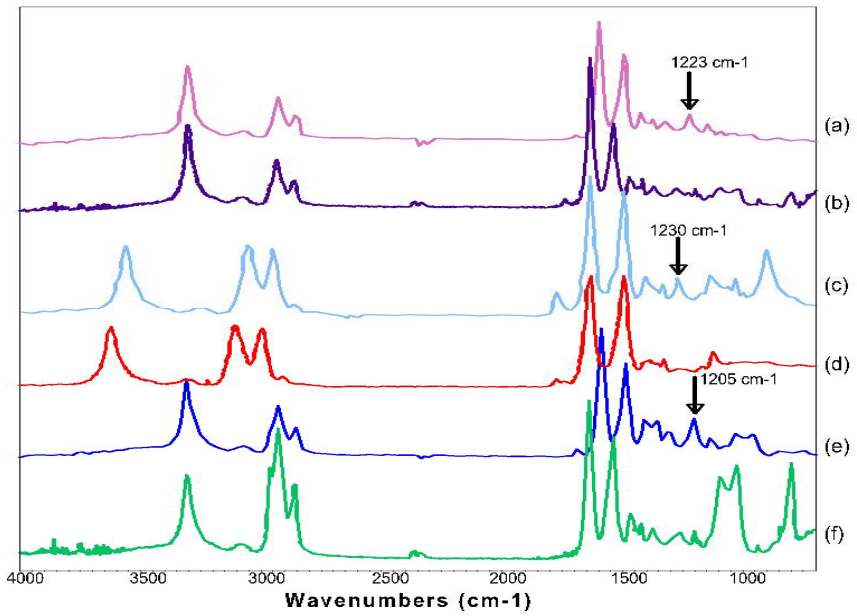


Figure 4.46: FTIR spectra of the fabric samples after treatment with silver chloride (a) treated powernet warp, (b) untreated powernet warp control, (c) treated flat warp, (d) untreated flat warp control, (e) treated weft, (f) untreated weft control knitted fabric samples.

4.5.6 PHMB antimicrobial agent

In order to identify the infrared absorption spectrum and detect any changes in the structure of the PHMB treated samples during treatment, treated samples were scanned using a Nicolet Nexus 470 Spectrophotometer with AVATAR Omni Sampler for Attenuated Total Reflectance (ATR) mode. The aggregated scans showing the absorbance across the infrared spectrum was acquired using OMNIC™ software.

Figure 4.47 shows FTIR spectra of untreated and treated fabric samples with PHMB. PHMB has a strong absorbance between 1200 and 1700 cm^{-1} [153]. Spectral comparisons of (a) treated powernet warp knitted showed the absorption bands (1250 cm^{-1} and 1350 cm^{-1}) in the spectrum, (b) untreated powernet warp control fabric showed no absorption bands between 1200cm^{-1} and 1700cm^{-1}, (c) treated flat warp knitted fabric showed the absorption bands (1250 cm^{-1} and 1350 cm^{-1}) in the spectrum, (d) untreated flat warp control fabric showed no absorption bands between 1200cm^{-1} and 1700cm^{-1}, (e) treated weft knitted fabric showed the absorption bands (1250 cm^{-1} and 1350 cm^{-1}) in the spectrum, (f) untreated weft control knitted fabric samples showed no absorption bands between 1200cm^{-1} and 1700cm^{-1}.

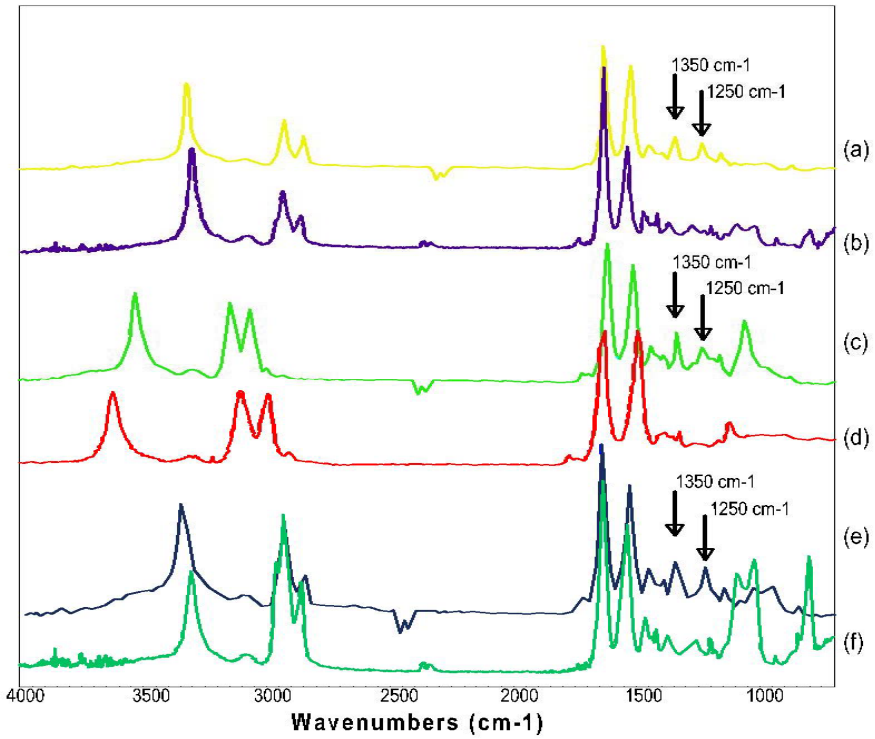


Figure 4.47: FTIR spectra of the fabric samples after treatment with PHMB (a) treated powernet warp, (b) untreated powernet warp control, (c) treated flat warp, (d) untreated flat warp control, (e) treated weft, (f) untreated weft control knitted fabric samples.

4.6 Physical and Mechanical Properties

Physical and mechanical properties were tested in order to evaluate the fabric properties in terms of bursting strength, air permeability, stiffness and drapeability before and after antimicrobial treatments.

4.6.1 Bursting strength

Bursting strength was tested by following ASTM D3787 using Ball Bursting Scott Tester. The results are shown in Figures (4.48 – 4.50). A small significant decrease in bursting strength was observed after antimicrobial treatments. Lowest values were obtained for samples treated with PHMB. This is attributed to cross linker in the antimicrobial solution. It is thought to decrease the elasticity of the fabric resulting in a decrease to the bursting strength of the fabrics samples.

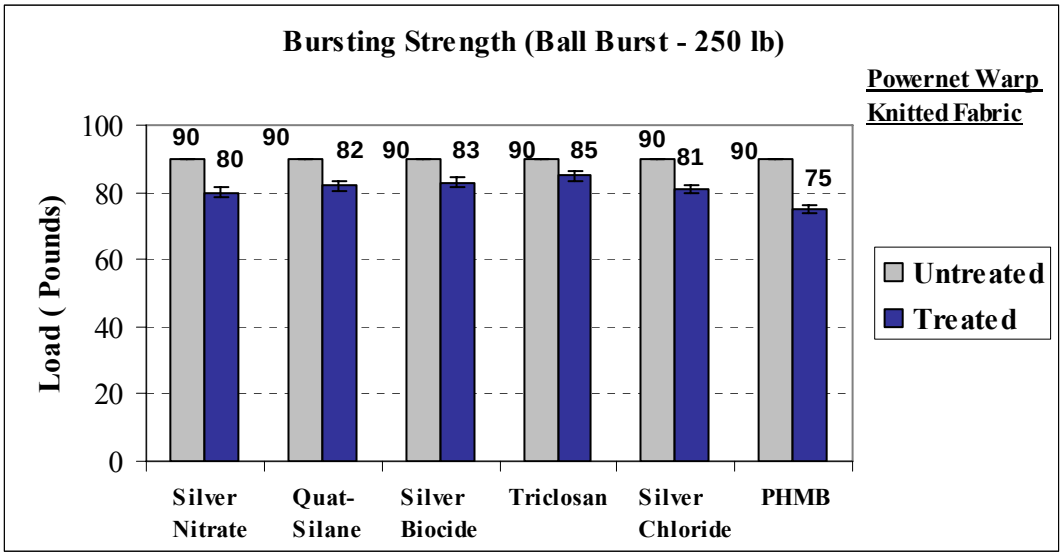


Figure 4.48: Bursting strength for untreated and treated powernet warp knitted fabric samples.

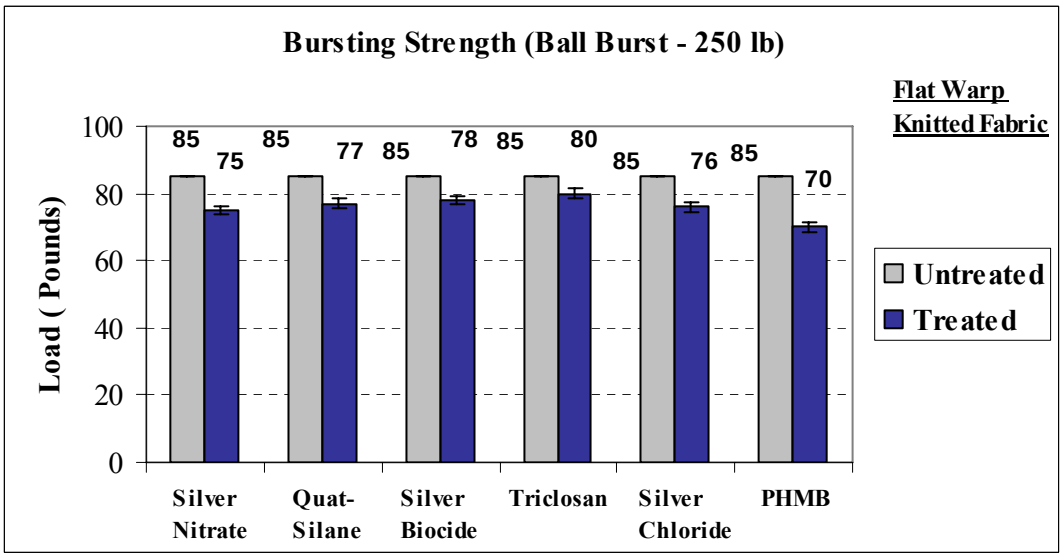


Figure 4.49: Bursting strength for untreated and treated flat warp knitted fabric samples.

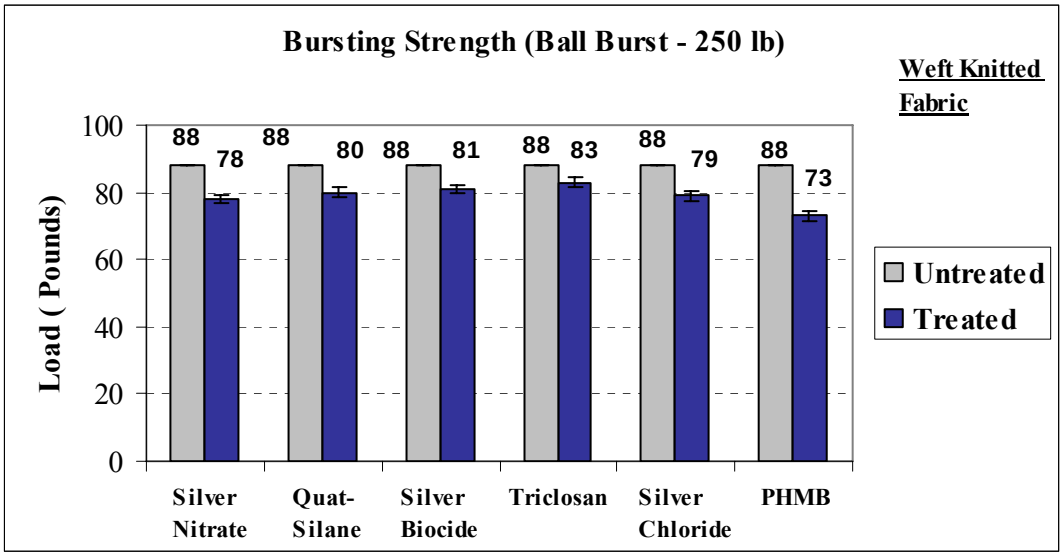


Figure 4.50: Bursting strength for untreated and treated weft knitted fabric samples.

4.6.1.1 Effect of type of antimicrobial agent on bursting strength

ANOVA one-way was used to analyze the effect of type of antimicrobial agent on bursting strength. Using one way analysis of variance, p-value was found as 0.01. The result of the analysis was shown in Table 4.43. As p-value is smaller than 0.05, it can be estimated that types of antimicrobial agent had a significant effect on bursting strength.

Table 4.43: ANOVA and estimation of parameters from bursting strength.

ANOVA one way						
Source of Variance	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	80.0833	1	80.0833	8.1028	0.0173	4.9646
Within Groups	98.8333	10	9.8833			
Total	178.9166	11				

4.6.2 Air permeability

Air permeability was tested by following ASTM D737 by using Fraiser Air Permeability Tester.

- For Powernet fabrics;
  - 2,75 inch test area (relaxed state)
  - Orifice Diameter = 16mm

- For Weft knitted fabrics;
  - 2,75 inch test area (relaxed state)
  - Orifice Diameter = 8mm
- For Warp knitted fabrics;
  - 2,75inch test are (relaxed state)
  - Orifice Diameter = 6mm

A small significant decrease in air permeability was observed after antimicrobial agent procedures. Powernet fabrics showed the highest air permeability before and after treatments while weft knitted fabrics showed the lowest air permeability. The results are presented in Figures (4.51-4.56).

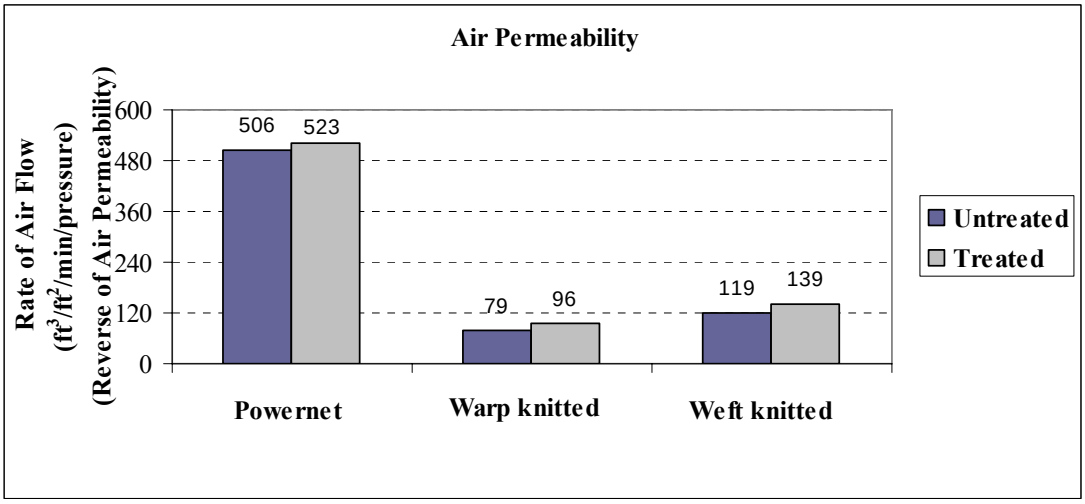


Figure 4.51: Air permeability for untreated and treated samples with silver nitrate.

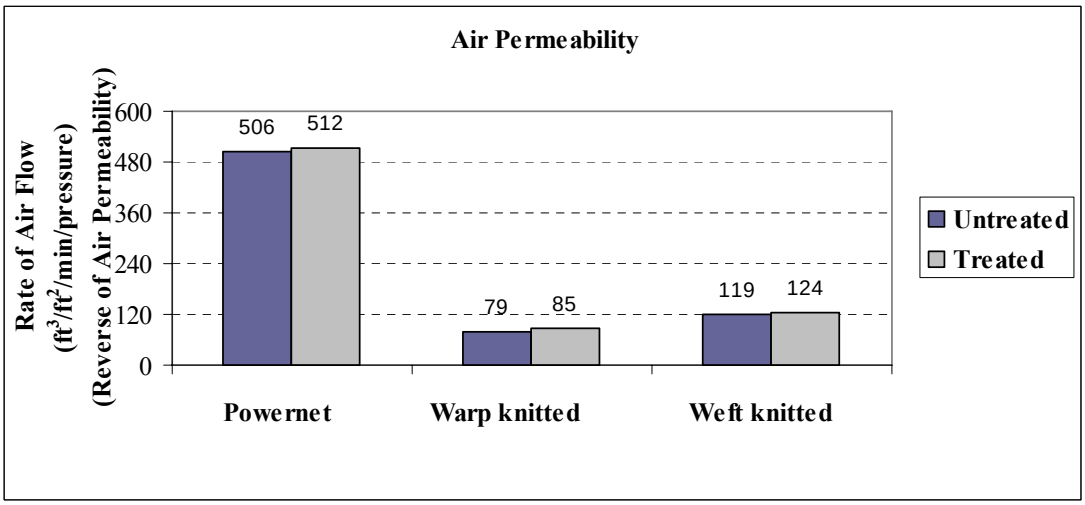


Figure 4.52: Air permeability for untreated and treated samples with quat-silane.

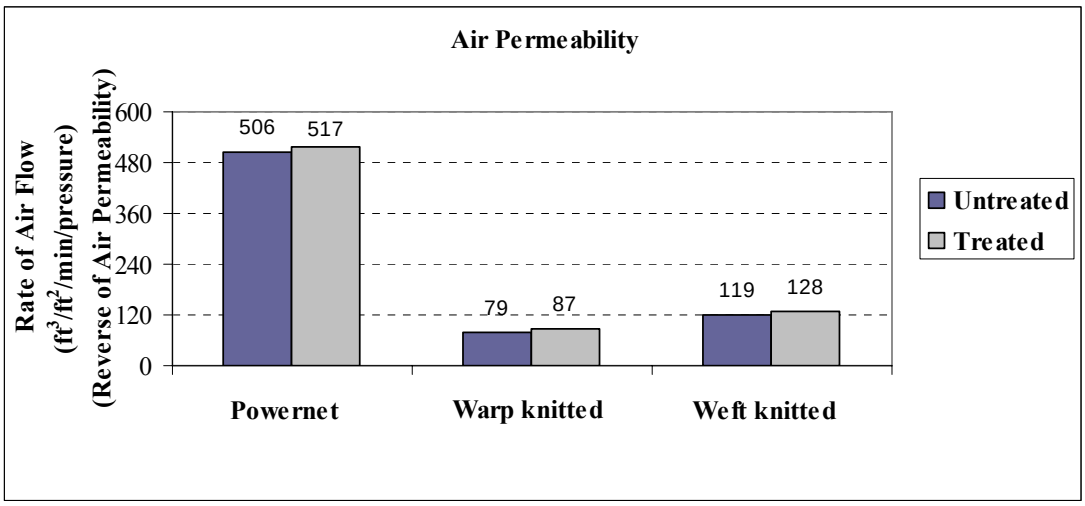


Figure 4.53: Air permeability for untreated and treated samples with silver biocide.

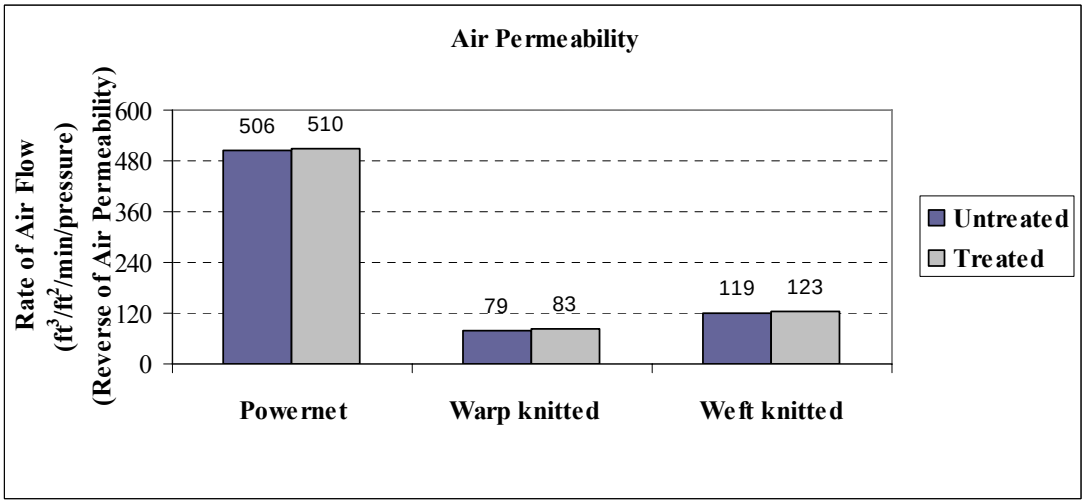


Figure 4.54: Air permeability for untreated and treated samples with Triclosan.

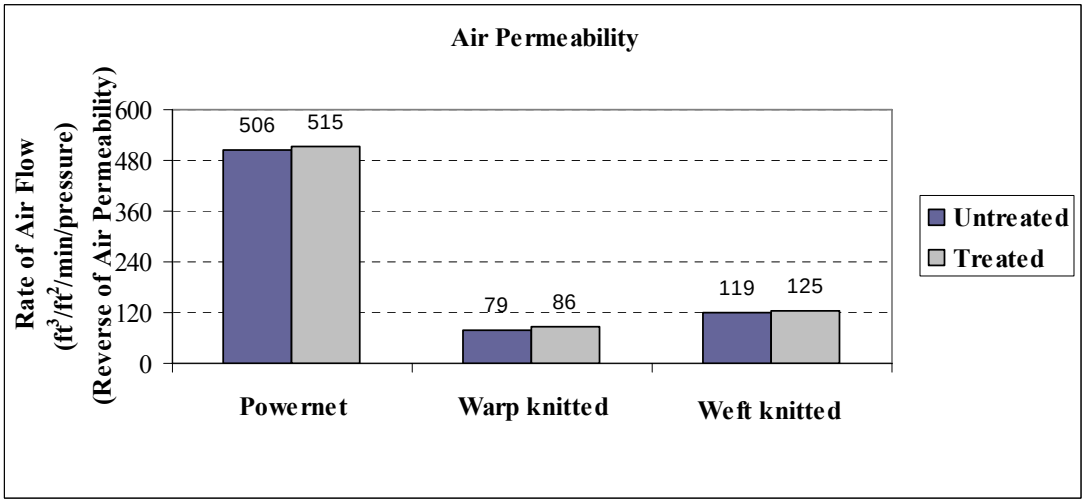


Figure 4.55: Air permeability for untreated and treated samples with silver chloride.

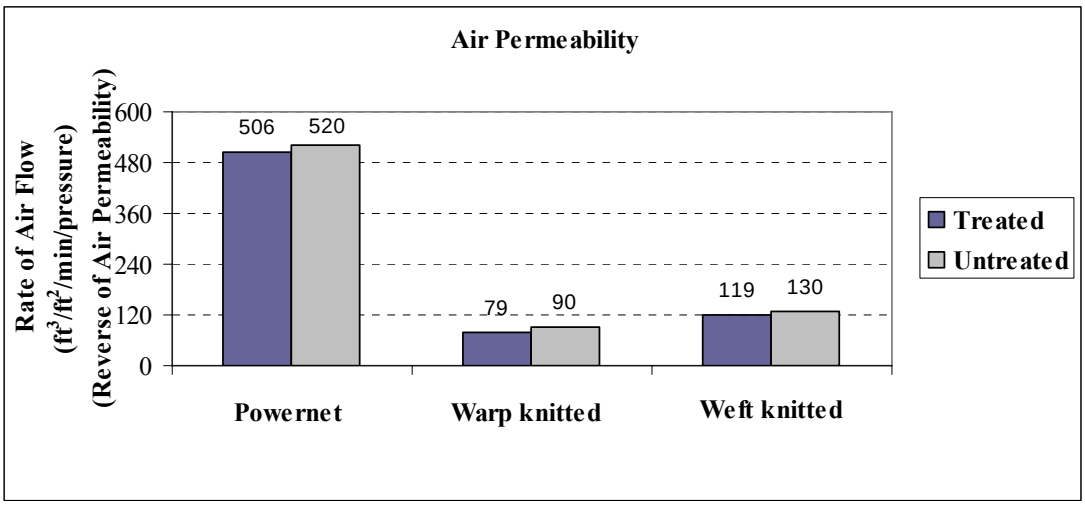


Figure 4.56: Air permeability for untreated and treated samples with PHMB.

The amount of finish and coating applied on the fabric may have an effect upon air permeability by bringing a change in the length of airflow paths through a fabric. Air permeability are also related with thermal comfort of fabrics. When the results are compared with parachute nylon/spandex fabrics, the rate of air flow is between ($200ft^3/ft^2$/min/pressure). This shows us the fabrics have a good air permeability even after all antimicrobial treatments. Powernet fabric samples showed the highest air permeability before and after treatment among the other treatments. The powernet fabrics were found the least elastic fabrics by stretch tests when compared with flat warp and weft knitted structures (can be seen in section 4.6.5). The results can be attributed to that. Additionally, the tightness, thickness, porosity, construction, geometry of the fabric and the fabric cover factor (fabric surface structure/ total fabric surface) are important aspects of air permeability.

4.6.2.1 Effect of type of antimicrobial agent on air permeability

ANOVA one-way was used to analyze the effect of type of antimicrobial agent on air permeability. Using one way analysis of variance, p-value was found as 0.008. The result of the analysis was shown in Table 4.44. As p-value is smaller than 0.05, it can be estimated that types of antimicrobial agent had a significant effect on bursting strength.

Table 4.44: ANOVA and estimation of parameters from air permeability.

ANOVA one way						
Source of Variance	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	560.3333	1	560.3333	21.8595	0.0008	4.9646
Within Groups	256.3333	10	25.63333			
Total	816.6666	11				

4.6.3 Stiffness

Stiffness was tested in cross and machine direction by following ASTM D5732, method using the Stiffness Cloth Tester, IDM Instrument. The results are presented in Figures (4.57- 4.62). The stiffness showed an increase for all fabric samples after antimicrobial treatments for all types of antimicrobial chemicals. The treated samples with PHMB showed the highest stiffness followed by silver nitrate treated samples. This is attributed to the cross-linker used for the antimicrobial solution as an auxiliary chemical. The high stiffness of the PHMB treated samples was easily observed also by hand. The samples treated with silver nitrate also gave higher stiffness values. This is attributed to polyurethane and epoxy resin auxiliary chemicals in the antimicrobial solutions.

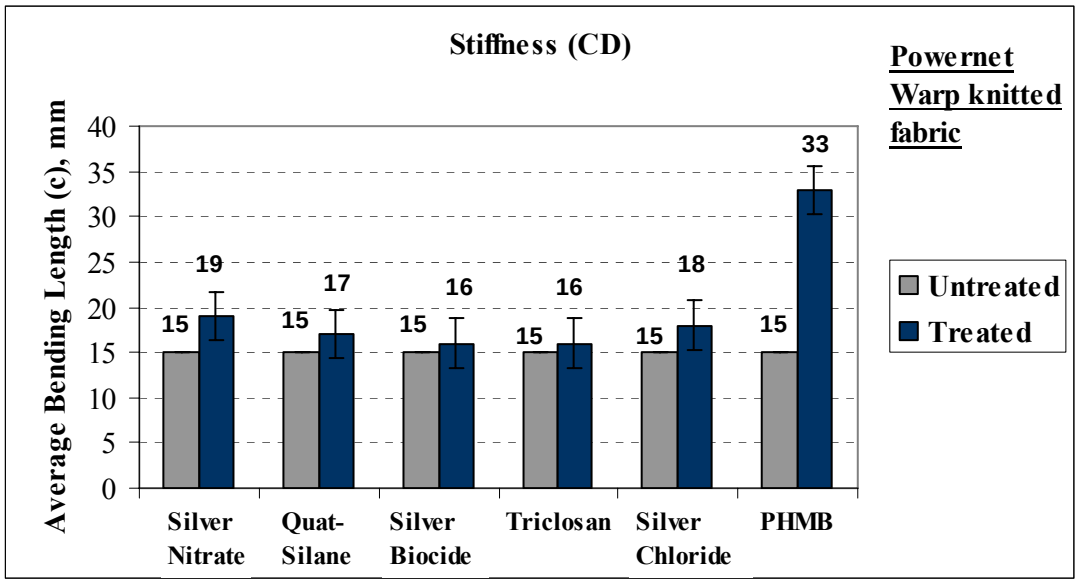


Figure 4.57: Stiffness (CD) for untreated and treated samples for powernet warp knitted fabrics.

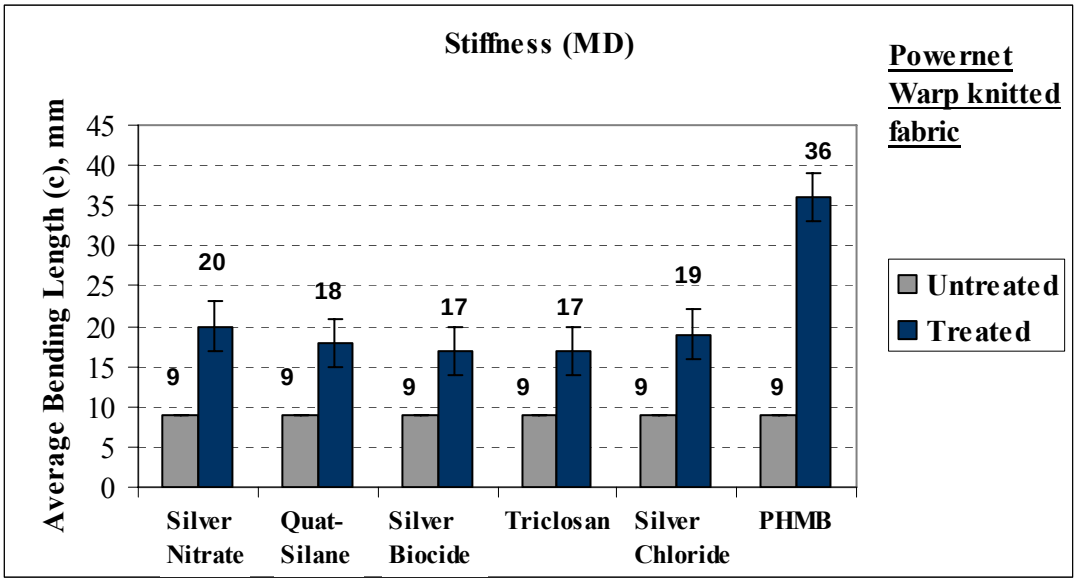


Figure 4.58: Stiffness (MD) for untreated and treated samples for powernet warp knitted fabrics.

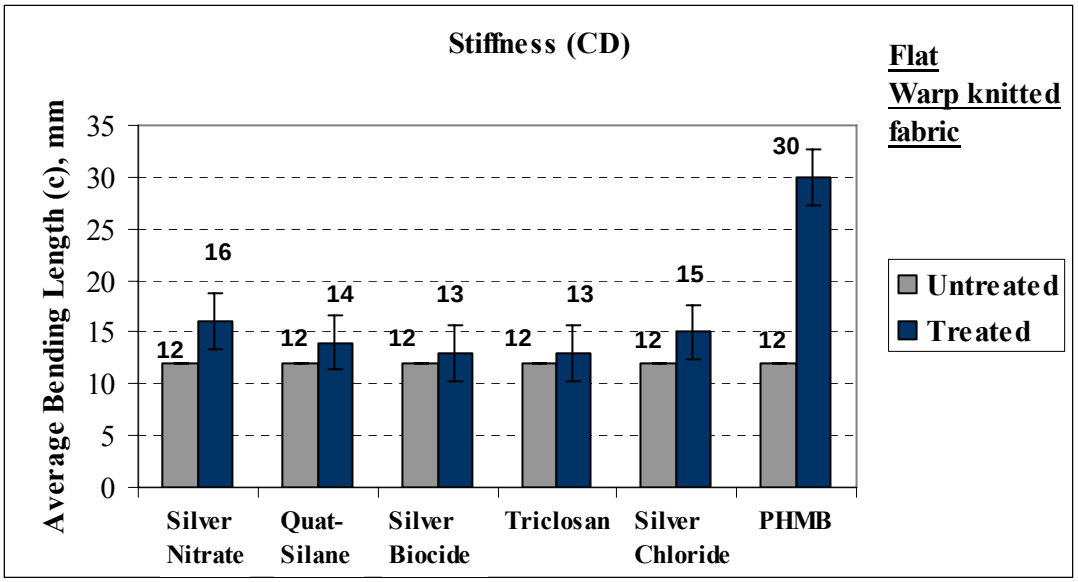


Figure 4.59: Stiffness (CD) for untreated and treated samples for flat warp knitted fabrics.

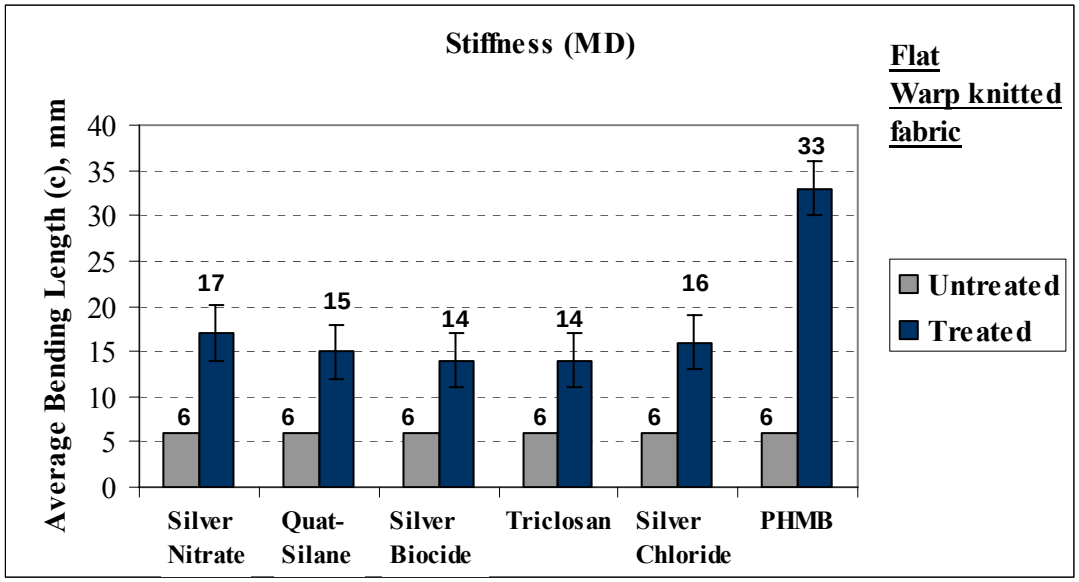


Figure 4.60: Stiffness (MD) for untreated and treated samples for flat warp knitted fabrics.

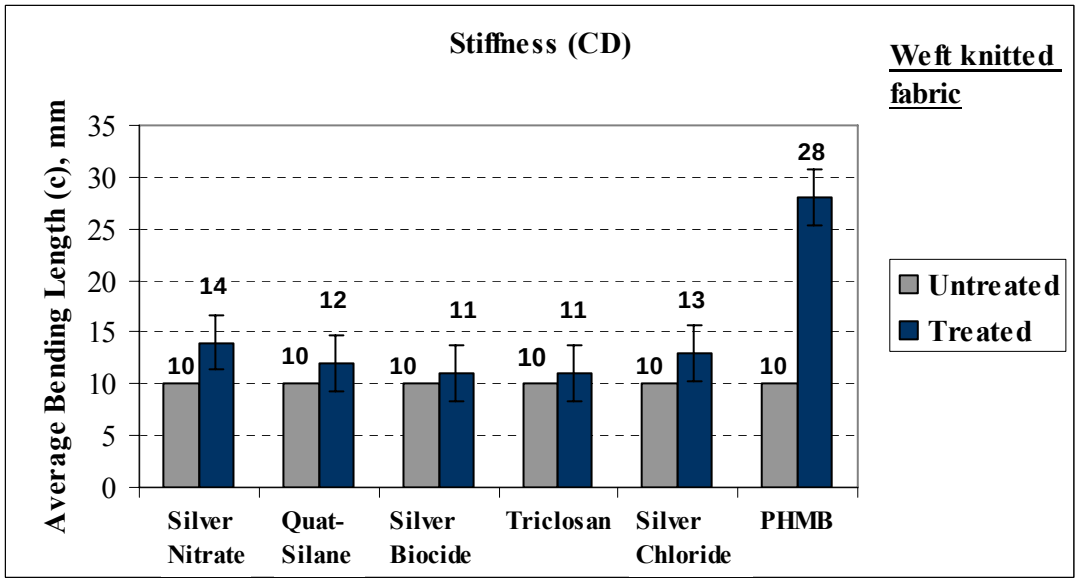


Figure 4.61: Stiffness (CD)for untreated and treated samples for weft knitted fabrics.

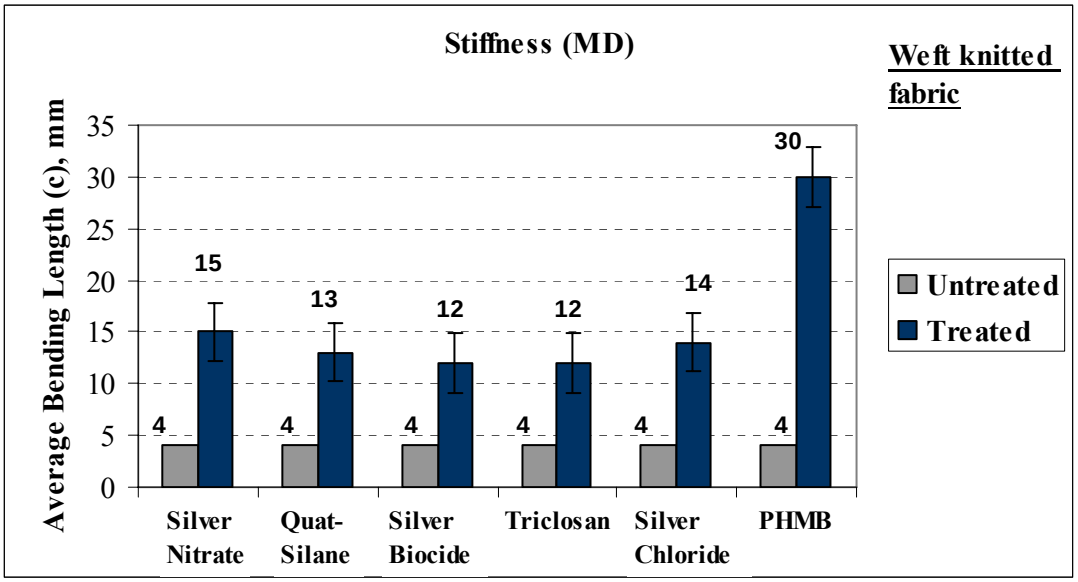


Figure 4.62: Stiffness (MD) for untreated and treated samples for weft knitted fabrics.

4.6.3.1 Effect of type of antimicrobial agent on stiffness

ANOVA one-way was used to analyze the effect of type of antimicrobial agent on stiffness. Using one way analysis of variance, p-value was found as 0.0005. The result of the analysis was shown in Table 4.45. As p-value is smaller than 0.05, it can be estimated that types of antimicrobial agent had a significant effect on stiffness.

Table 4.45: ANOVA and estimation of parameters from stiffness.

ANOVA one way						
Source of Variance	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	425.0417	1	425.0417	16.4363	0.0005	4.3009
Within Groups	568.9167	22	25.85985			
Total	993.9583	23				

4.6.4 Drapeability

Drapeability was tested by following BS 5058 using Cusick Drapemeter. The results are presented in Figures (4.63-4.65). The drapeability was decreased for all fabric samples after treatment with all antimicrobial chemicals. This is attributed to the decrease in elasticity of the fabric samples after antimicrobial treatments. Powernet warp knitted fabrics showed the lowest drapeability and this is attributed to more open and least elastic structure of powernet warp knitted fabrics when compared with the other two fabrics (also can be seen in section 4.6.5).

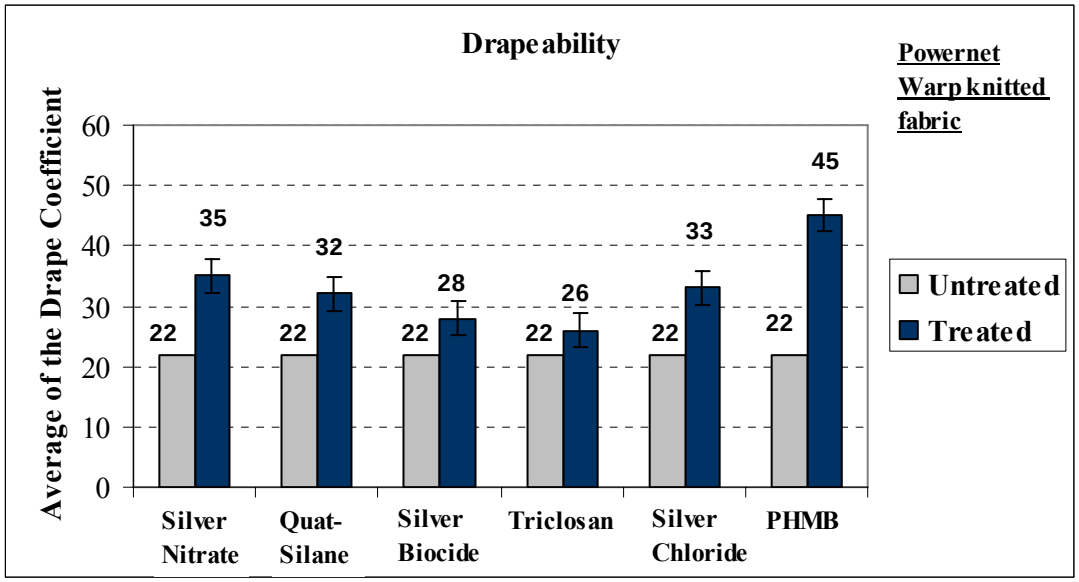


Figure 4.63: Drapeability for untreated and treated powernet warp knitted fabrics.

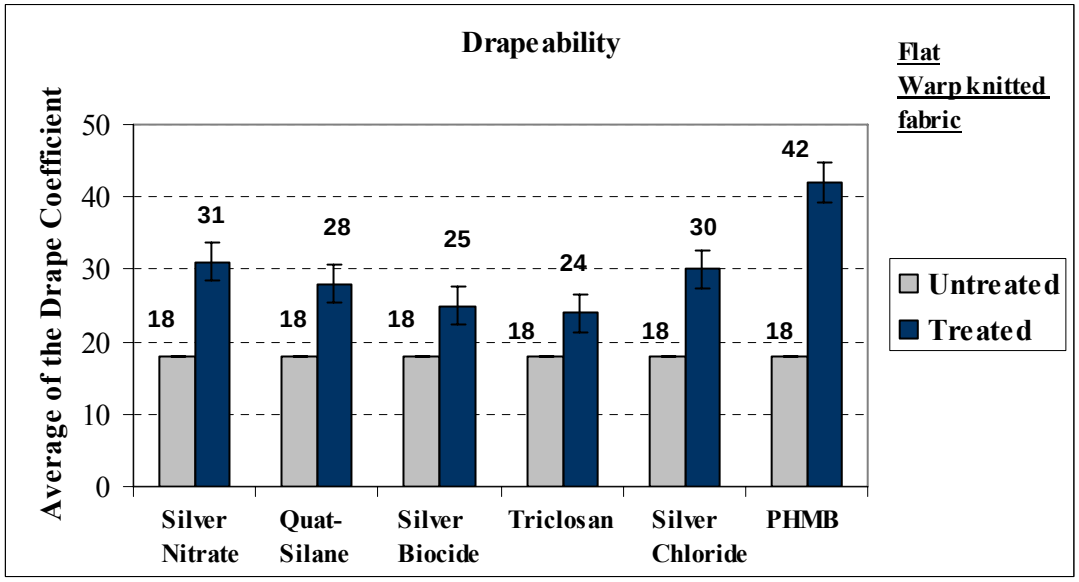


Figure 4.64: Drapeability values for untreated and treated flat warp knitted fabrics.

Weft knitted fabric samples showed the highest drapeability before and after treatment and this is due to weft knitted fabrics are more elastic than powernet warp knitted fabrics. Treated samples with PHMB showed the lowest drapeability and this is attributed to the antimicrobial treatment procedure to link the PHMB to Nylon/spandex fabrics by crosslinking which caused an increase in stiffness and a decrease in drapeability. Drapeability also can give an idea about comfortable wearing performance. It may not be evaluated or seen at the use, but about the fabric texture.

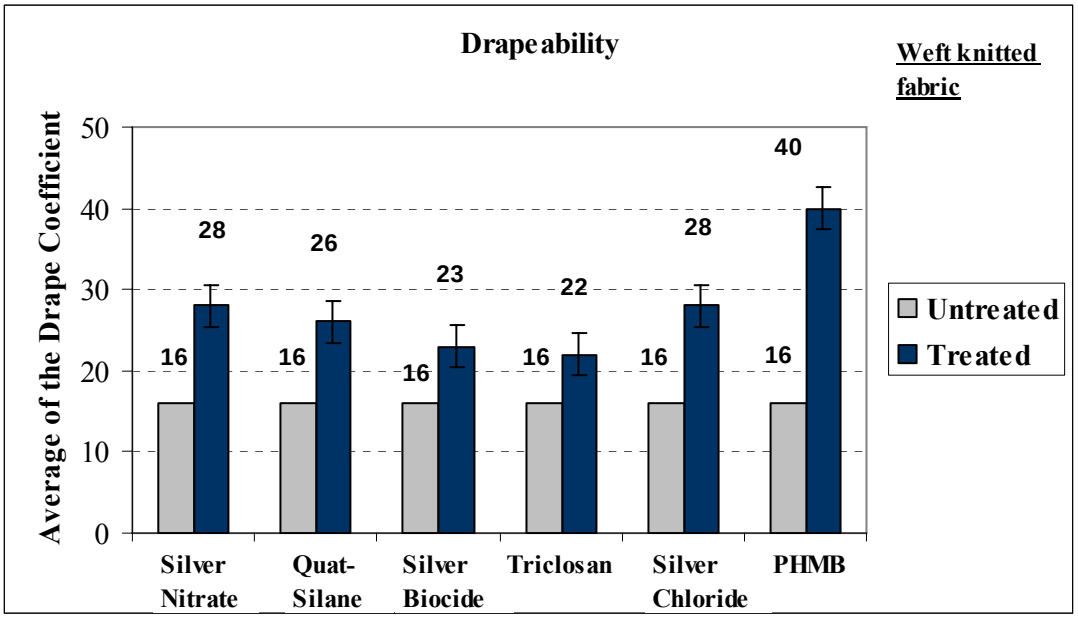


Figure 4.65: Drapeability values for untreated and treated weft knitted fabrics.

4.6.4.1 Effect of type of antimicrobial agent on drapeability

ANOVA one-way was used to analyze the effect of type of antimicrobial agent on drapeability. Using one way analysis of variance, p-value was found as 0.003. The result of the analysis was shown in Table 4.46. As p-value is smaller than 0.05, it can be estimated that types of antimicrobial agent had a significant effect on drapeability.

Table 4.46: ANOVA and estimation of parameters from drapeability.

ANOVA one way						
Source of Variance	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	456.3333	1	456.3333	14.5483	0.0034	4.9646
Within Groups	313.6666	10	31.3666			
Total	770	11				

4.6.5 Time dependent fabric growth of knitted fabrics

Method based on ASTM D2594 Test Method was followed to test the fabric growth of the fabrics. The test equipment was set up as shown in Figure 4.66. The bench marks were taken as 0.7cm for powernet warp knitted fabrics and 0.8cm for flat warp knitted fabrics in warp direction, and 0.9cm for weft knitted fabrics in weft direction. The fabrics were tested and the fabric growth behavior was observed during 12 weeks. The results are presented in Figures (4.67 – 4.69). For four weeks all fabrics showed not any change in fabric growth. According to the records after four weeks, a

small significant change in fabric growth were observed and recorded and calculated using Eq. 4.3.

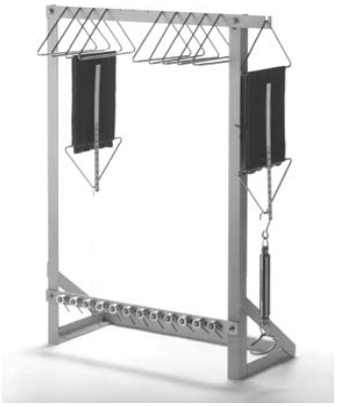


Figure 4.66: Testing the time dependent fabric growth of knitted fabrics.

Fabric Growth $_{60s}$, % = 100 X (B – A) / A **(4.3)**

A = Original distance btw. bench marks prior to tension force, mm (in.)

B = Distance btw. bench marks, mm (in.) measured after release of the tension, force following 60s. recovery.

Weights were attached to the bottom hanger of the hanger assembly, providing total tensions of 2,27kg to the specimen ± 1%.

$A_{powernet}$ = 0,70cm

$B_{powernet}$ = 0,71cm

$A_{flat\ warp}$ = 0,80cm

$B_{flat\ warp}$ = 0,81cm

$A_{weft\ knitted}$ = 0,90cm

$B_{weft\ knitted}$ = 0,91cm

For the fabric growth, the average of two specimens to the nearest 1% was calculated as below:

For powernet fabric: 1.43 %

Flat warp knitted fabric: 1.25 %

Weft knitted fabrics: 1.1%

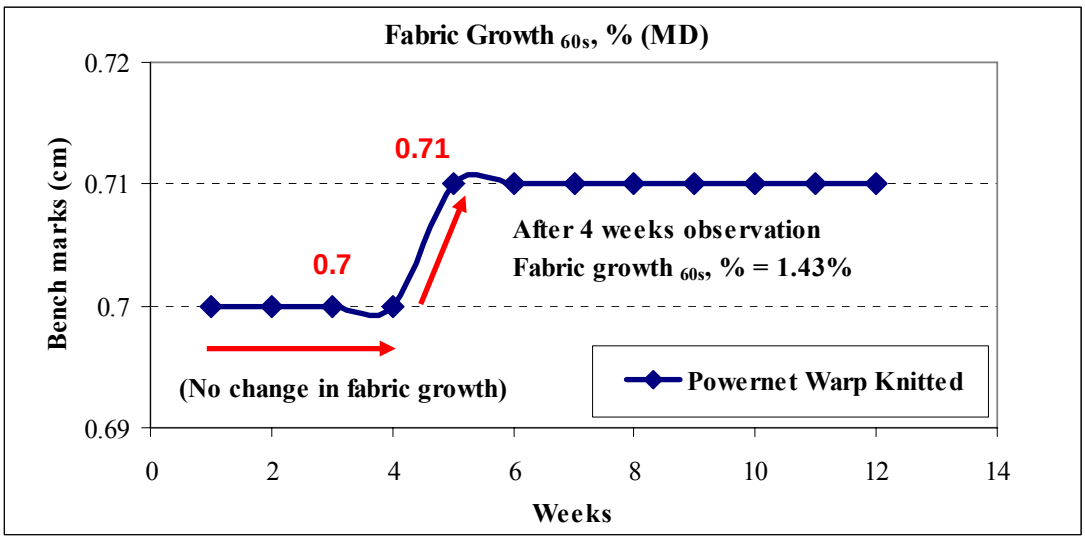


Figure 4.67: Fabric growth for powernet warp knitted fabrics.

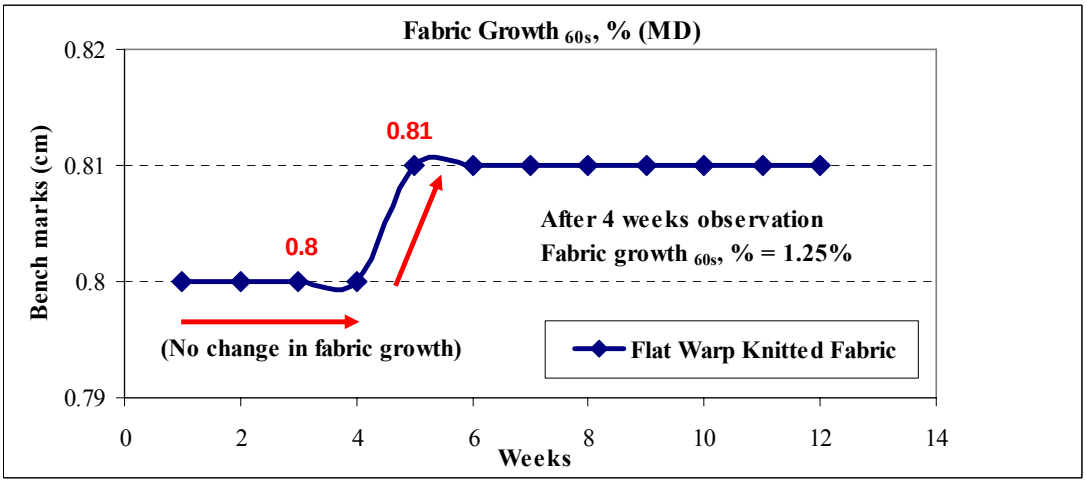


Figure 4.68: Fabric growth for flat warp knitted fabrics.

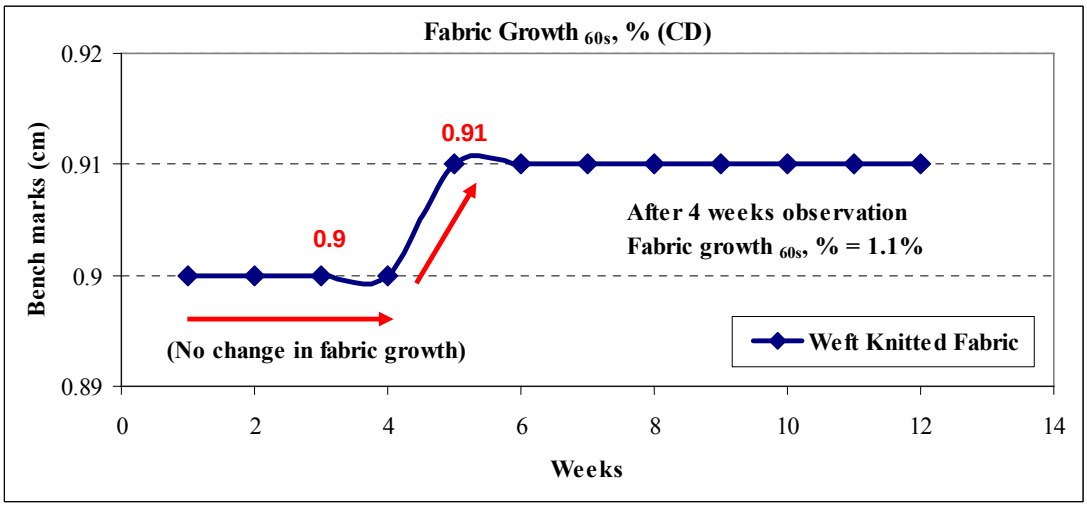


Figure 4.69: Fabric growth for weft knitted fabrics.

These results also can give an idea about the wearing performances of these garments. They are usually worn for up to two years until they lose the tension that they are required to give.

Weft knitted fabrics were observed as more elastic than powernet and flat warp knitted fabrics. It is attributed to more elastic structure of weft knitted fabrics than warp knitted fabrics.

4.6.6 Fabric structural properties and porosity

Fabric structural properties and porosity properties were tested and calculated using Eq. 4.4. and the results are presented in Table 4.47. Pad-dry-cure and exhaustion control samples were identified without using any antimicrobial agent.

$$\varepsilon = (1 - \rho_a / \rho_b) \quad \textbf{(4.4)}$$

ε = Fabric porosity

ρ_a = Fabric density (g/cm^3) = [(Fabric weight per unit area) / Fabric thickness]

ρ_b = Fiber density (g/cm^3), for $\rho_{nylon\ 6.6} = 1.14\ g/cm^3$

Table 4.47: Fabric structural properties and porosity.

Samples	Courses per cm	Wales per cm	Weight (g/m^2)	Fabric thickness (mm)	Porosity, %
Powernet silver nitrate	14	16	246	0.60	0.64
Flat warp silver nitrate	26	20	169	0.68	0.73
Weft silver nitrate	20	22	282	0.83	0.70
Powernet Quat-Silane	14	18	244	0.63	0.66
Flat warp Quat-Silane	22	24	167	0.70	0.79
Weft Quat-Silane	20	20	277	0.82	0.70
Powernet PHMB	12	17	256	0.67	0.67
Flat warp PHMB	25	21	180	0.73	0.79
Weft PHMB	20	22	290	0.89	0.72
Powernet Triclosan	13	17	255	0.65	0.65
Flat warp Triclosan	24	20	177	0.70	0.78
Weft Triclosan	20	14	287	0.85	0.71
Powernet silver chloride	13	18	242	0.58	0.63
Flat warp silver chloride	23	19	165	0.65	0.77
Weft silver chloride	22	15	278	0.80	0.69
Powernet silver biocide	13	17	245	0.58	0.63
Flat warp silver biocide	27	20	167	0.67	0.78
Weft silver biocide	19	24	280	0.68	0.64
Powernet scoured/prewashed control	13	17	243	0.58	0.68
Flat warp scoured/prewashed control	27	20	166	0.68	0.81
Weft scoured/prewashed control	18	26	279	0.70	0.69
Powernet pad-dry-cure control	13	18	252	0.60	0.67
Flat warp pad-dry-cure control	23	21	173	0.69	0.80
Weft pad-dry-cure control	18	22	283	0.73	0.70
Powernet exhaustion control	13	17	253	0.62	0.69
Flat warp exhaustion control	24	20	175	0.69	0.80
Weft exhaustion control	17	21	284	0.82	0.73

Fabric thickness values for treated samples are higher than those for untreated and washed ones due to a small significant increase in course and wales per cm and shrinkage upon washing. Fabric thickness values for weft knitted fabrics were found higher than warp knitted fabrics for both control and treated samples. This is attributed to higher bulkiness of weft knitted fabrics than warp knitted fabrics. Fabric thickness values for treated samples with PHMB antimicrobial agents are higher than those for treated with other ones due to crosslinking of PHMB to Nylon/spandex fabrics which caused a swelling of fibers during processing. Porosity values are higher for flat warp knitted fabrics than powernet warp knitted and weft knitted fabrics for control and treated samples due to high fabric density. Porosity values were found not any different for control and treated samples. This is attributed to high elastane percentage in fabric structures. The tightness of the fabric was observed as an important aspect of porosity.

It's found the antimicrobial chemistry altered the mechanical and physical properties of the treated samples and thermal conditions as temperature, duration of the application did not alter the the mechanical and physical properties of the treated samples.

4.7 Comfort Properties

The thermophysiological properties were tested in order to evaluate the comfort performance of the burn garments which are worn for up to two years. Pressure garments should protect their thermophyiological comfort properties before and after antimicrobial treatments. For this, untreated and treated fabric samples were tested in terms of thermal resistance (R_{ct}) and isolation properties (clo unit). The results are presented in Tables (4.48 - 4.53). A small siginificant increase was observed in terms of thermal resistance (R_{ct}) (Tog) and isolation (I_t) (clo) properties for fabrics samples after treated with different types of antimicrobials.

Total Thermal Resistance (R_{ct}), [(°ΔC)(m^2)/W], the total resistance to dry heat transfer (insulation) for a fabric system including the surface air layer.

Total Insulation Value (I_t), [clo], indicates the thermal resistance measured in units of clo which indicates the insulating ability of the test material.

Table 4.48: Sweating thermal hot plate results for untreated and treated with silver nitrate samples.

Fabric Samples	Untreated		Treated	
	R_{ct}	I_t	R_{ct}	I_t
Powernet warp knitted	0.060	0.387	0.062	0.400
Flat warp knitted	0.076	0.488	0.077	0.495
Weft knitted	0.072	0.465	0.073	0.470

Table 4.49: Sweating thermal hot plate results for untreated and treated with Quat-Silane samples.

Fabric Samples	Untreated		Treated	
	R_{ct}	I_t	R_{ct}	I_t
Powernet warp knitted	0.060	0.387	0.061	0.394
Flat warp knitted	0.076	0.488	0.077	0.495
Weft knitted	0.072	0.465	0.073	0.470

Table 4.50: Sweating thermal hot plate results for untreated and treated with Silver Biocide samples.

Fabric Samples	Untreated		Treated	
	R_{ct}	I_t	R_{ct}	I_t
Powernet warp knitted	0.060	0.387	0.061	0.394
Flat warp knitted	0.076	0.488	0.077	0.495
Weft knitted	0.072	0.465	0.073	0.470

Table 4.51: Sweating thermal hot plate results for untreated and treated with Triclosan samples.

Fabric Samples	Untreated		Treated	
	R_{ct}	I_t	R_{ct}	I_t
Powernet warp knitted	0.060	0.387	0.061	0.394
Flat warp knitted	0.076	0.488	0.077	0.495
Weft knitted	0.072	0.465	0.073	0.470

Table 4.52: Sweating thermal hot plate results for untreated and treated with Silver Chloride samples.

Fabric Samples	Untreated		Treated	
	R_{ct}	I_t	R_{ct}	I_t
Powernet warp knitted	0.060	0.387	0.061	0.394
Flat warp knitted	0.076	0.488	0.077	0.495
Weft knitted	0.072	0.465	0.073	0.470

Table 4.53: Sweating thermal hot plate results for untreated and treated with PHMB samples.

Fabric Samples	Untreated		Treated	
	R_{ct}	I_t	R_{ct}	I_t
Powernet warp knitted	0.060	0.387	0.062	0.400
Flat warp knitted	0.076	0.488	0.077	0.495
Weft knitted	0.072	0.465	0.073	0.470

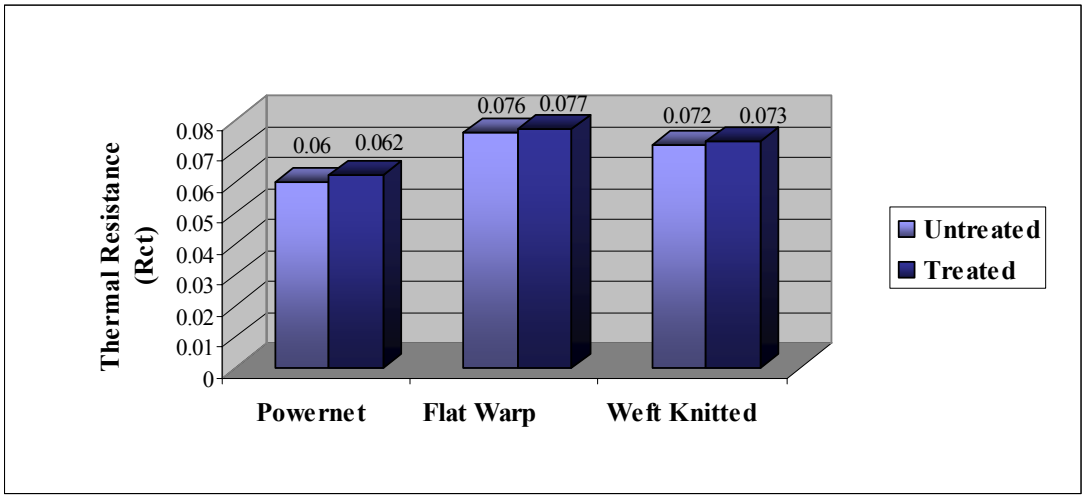


Figure 4.70: A comparison of thermal resistance for treated and control samples.

The results were compared with a standard sportwool of a famous football team to have an idea about the evaluation of the thermophysiological comfort properties of the fabric samples [9]. Thermal resistance values of the fabric samples varies from 0.060 m^2K^o/W to 0.077 m^2K^o/W while the thermal resistance results for a comfortable sportwool is 0.088 m^2K^o/W. And this comparison can be evaluated as the fabric samples are comfortable in terms of thermophysiological comfort

properties. A comparison of thermal resistance for treated and control samples is shown as in Figure 4.70. Fabric construction, thickness, tightness, and the cover factor of the structure are important factors on the thermophysiological comfort properties of fabrics.

4.7.1 Correlation between the thermal resistance for control and treated samples

Thermal resistance were measured from control and treated samples. Regression analysis of the results showed that there was a correlation between control and treated samples with as the lineer formula, $y = 0.2148x - 0.0482$, $R^2 = 0.9511$ as shown in Figure 4.71. It is observable from the figure that thermal resistance for control and treated samples were strongly correlated. Antimicrobial treatment procedures had a significant effect on thermal resistance.

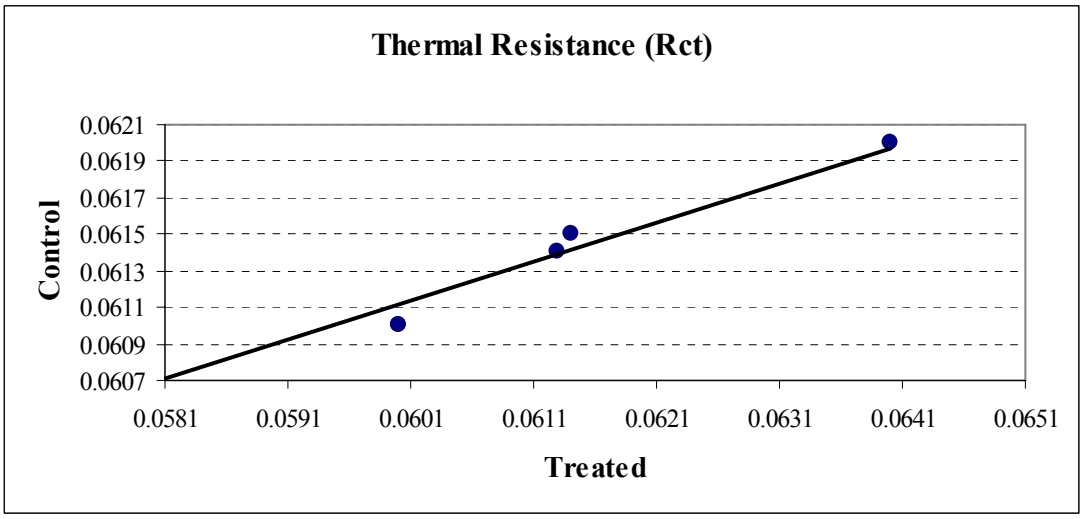


Figure 4.71: Thermal resistance for treated samples from control samples.

5. CONCLUSIONS

Medical textile sector focused on antimicrobial finishes developing quality on rehabilitation by increasing the effectiveness and functions. Burn pressure garment industry is one of the crucial markets since millions of burn accidents are being reported every year. The rehabilitation expenses for burn injuries are the highest when compared with other injuries [204]. The research is based on imparting durable antimicrobial characteristics to elastomeric fabrics for burn pressure garments to provide infection protection by improving the healing properties. Novel elastomeric fabrics for burn pressure garments were developed having durable antimicrobial property using various antimicrobial technologies.

XPS, SEM and FTIR analysis were conducted to examine the achievement of the treatments by using antimicrobial chemical agents on pressure garment fabrics. SEM analysis was used to determine the various antimicrobial solutions appeared on the fabric and fiber surfaces for all antimicrobial treated samples. FTIR analysis was used to identify the infrared absorption spectrum and detect any changes in the structure for all antimicrobial treated samples. XPS analysis was used to observe the silver efficacy of the treated samples by silver antimicrobial chemical agents.

Antimicrobial test results following AATCC 100 Test Method [185] showed 99% reduction of bacteria for powernet warp knitted fabrics treated with silver nitrate, silver chloride and PHMB antimicrobial agent procedures. For flat warp knitted and weft knitted fabrics treated with PHMB antimicrobial agent procedure also 99% reduction of bacteria was found. The percentage reduction of bacteria for fabric samples was found between (98.30% - 99.98%) for each antimicrobial agent procedure. Launderings applied to see the effectiveness of these antimicrobial agents in long term effectiveness. The antimicrobial activity remained the same after 5 launderings for fabric samples treated with six different antimicrobial treatments. A small significant decrease in antimicrobial activity was observed even after 50 launderings. 50 launderings equal to 1 year use for home use and 2 months for

hospital use due to laundering conditions in hospitals are more aggresive. The results for bacterial reductions for each antimicrobial agent procedure were satisfying for fabric samples. These treatments also yield good results to prevent odor, decrease infection by preventing and/or blocking microbial growth according to the antimicrobial mechanism and support reducing of scarring by providing a hygienic environment around the scar. Antimicrobial finish inhibits odor-causing microorganisms from colonizing and growing in the textile and thus prevents microorganisms from degrading the product. These are also good results to decrease costs by providing an appropriate level of rehabilitation.

Commercial wireless pressure sensors were used to control the pressures of burn pressure garments at an acceptable optimal medical range (0-15mmHg) before and after each antimicrobial treatment. Wireless pressure sensors were used for the first time in this study while imparting an antimicrobial activity to burn pressure garments. Treatments were conducted under controlled pressures before and after each antimicrobial agent procedure. Pressure measurements were taken from calf and ankle after each antimicrobial agent procedure for each pressure garment. The pressures for the ankle by confirming the Laplace equation gave the highest pressures before and after each antimicrobial treatment. Higher pressures were found after six antimicrobial treatments for three different fabrics. Weft knitted garments gave the highest pressures (5.7mmHg-6.3mmHg) before and after each antimicrobial agent procedure while the lowest pressures (5.0mmHg- 5.6mmHg) were observed for powernet warp knitted garments. It's found that the elasticity showed a small significant decrease and it has attributed due to a small significant shrinkage during processes. The pressures were measured between (5.0mmHg-6.3mmHg) which is in the acceptable optimal medical range that reduces the degree of hypertrophy, encourages the formation of normal pliable skin tissue and reduces the extent of scarring. A random pressure (at low-pressure class) value was picked for this work. They are usually custom-made garments and the pressures are usually determined by using lower or higher sizes of garments which vary for each patient and the rehabilitation procedure.

Physical and mechanical properties were also tested in terms of air permeability, bursting strength, stiffness and drapeability. The air permeability, the bursting strength and the drapeability showed a small significant decrease after antimicrobial

agent procedures while the stiffness showed a small significant increase for fabric samples. This is attributed to a small significant decrease in elasticity after processes. Lowest bursting strength and drapeability values and highest stiffness values were found for fabric samples treated with PHMB antimicrobial agents. This is attributed to bonding of antimicrobial chemical to the fibers by cross links which decreased the elasticity of the fabric samples by limiting the movement of fibers. Powernet fabric samples showed the highest air permeability before and after each antimicrobial treatment. This is attributed to more open structure of powernet fabrics. Highest air permeability were observed for weft knitted fabrics which is attributed to tighter structure of weft knitted fabrics when compared with warp knitted fabrics. Time dependent fabric growth of knitted fabrics was observed during 12 weeks. A small significant change in fabric growth were observed after four weeks. Weft knitted fabrics were found as more elastic than warp knitted fabrics. These results also can give an idea about the wearing performances of these garments. Usually pressure garments start to lose their elasticity minimum in 3 weeks and maximum in 3 months depending on the conditions. Fabric thickness values for treated samples with PHMB antimicrobial agents are higher than those for treated with other ones due to crosslinking of PHMB to Nylon/spandex fabrics which caused a swelling of fibers during processing. Porosity values are higher for flat warp knitted fabrics than powernet warp knitted and weft knitted fabrics for control and treated samples due to high fabric density. Porosity values were found not any different for control and treated samples. This is attributed to high elastane percentage in fabric structures. The tightness of the fabric was observed as an important aspect of porosity.

Also comfort properties were researched in terms of thermal resistance (R_{ct}) and isolation properties (I_t) in order to evaluate the comfort performances of fabric samples before and after antimicrobial treatments which are worn for up to two years. The thermophysiological test results showed that all treated samples with all antimicrobial agent procedures provide thermophysiological comfort. All test materials showed a small significant increase after each antimicrobial agent procedure. The powernet fabrics showed the lowest thermal resistance (0.394-0.400) while the flat warp knitted fabrics showed the highest thermal resistance (0.495). These results show that after antimicrobial treatments, the fabric samples can provide comfort by providing microclimate and preventing excess sweating of patients. This

will help to provide a hygienic environment during wound healing stage by eliminating allergic reactions which will help to prevent the risk of infection.

Since they offer different alternatives by having different antimicrobial mechanisms, various types of antimicrobial technologies were studied including silver compunds, polyhexamethylene biguanide (PHMB), quaternary ammonium compounds (QAC's) and Triclosan and various types of fabrics were developed using various types of antimicrobial agent procedures. Silver antimicrobials with many binding sites on their surfaces accelerate wound healing, while quaternary ammonium compounds are the most durable due to covalent bonding with textiles. Triclosan being a relatively small molecule, can also act like a disperse dye and can be used by exhaustion and are chemically stable, so that they're eliminated from the body slowly. But Triclosan safety is under review by the Food and Drug Administration (FDA) and Health Canada. It's found out that Triclosan is causing some allergic reactions and damaging immune system according to Hygiene Hypothesis. At lower concentrations, Triclosan appears bacteriostatic. PHMB overcomes fabric yellowing and can achieve a strong binding to the textile surface because of having a high molecular weight containing an average of 16 biguanide units in the polymer which provides more cationic sites per molecule.

6. RECOMMENDATIONS FOR FUTURE WORKS

The works that have been conducted in this research were focused on the development of novel elastomeric fabrics for burn pressure garments having durable antimicrobial activity using various technologies by controlling the pressures using wireless pressure sensors.

We outlined the optimum working conditions with antimicrobial agents for highly elastane fabrics that are used for the management of burn scars. It was difficult to study with hydrophobic highly elastane nylon fabrics to impart the functional finish because of low absorbency (%). First we made some trials using home washing for pretreatment, but the pick up that we observed was too low. So for pretreatment we validate a method to cope with the problem and applied Dupont procedure at which we got good results for increasing the pick up of the antimicrobial chemical agents. At this procedure, each sample was washed separately in different beakers using Ahiba Nuance machine. Then the samples were rinsed for 10 cycles in order to apply a pure rinsing before antimicrobial treatment procedures. Also before finishing, we made some trials on pick up using wetting agent in order to increase the pick up of the antimicrobial solution. It was not that different, so in order not to increase the variables in the study, we didn't use it. Another issue is, the stiffness showed a small significant increase after processing. For the first step, I didn't want to use more variables. I want to make some trials to eliminate this problem by using softeners.

This work is continuing with the application of different concentrations of different antimicrobial finishes to burn pressure fabrics with a view of to determining their effectiveness on compression function clinical and rehabilitation performance.

Animal tests can also be conducted to see the rehabilitation rates of these fabrics using a rat or mouse dorsal model. It can also give an idea about the elimination of allergic reactions on living organisms.

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Projects:

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