Comparison of the Effects of Nano and Conventional Crease Recovery Treatment Process Parameters

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ABSTRACT

COMPARISON OF THE EFFECTS OF NANO AND CONVENTIONAL CREASE RECOVERY TREATMENT PROCESS PARAMETERS

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To maintain fabric quality and comfort is coming into prominence every single day. It's possible to give fabrics some features by after-treatment processes. Due to these circumstances, textile finishing processes gain importance, especially easy care property can be desired by consumers. Growing technology causes innovations in textile finishing as well.

Nanotechnology can take part in textile industry both production of fibers and textile finishing chemicals. By improving nanotechnology in textile finishing, chemicals with different particle sizes are produced and used for commercial reasons.

In this study, chemicals with different particle size were applied via pad and newly developed foam application methods to 100% woven cotton fabric samples to make them crease resistant. After applications, drying and curing operations, some mechanical tests; abrasion resistance, crease recovery angle, tensile strength, tear strength and color difference by spectrophotometer were handled. By evaluating results of these mentioned tests, multi-axial graphics were drawn by MATLAB and the areas were calculated. These calculated areas lead us to find the best recipe.

Keywords: crease resistance, DMDHEU, particle size, cotton fabric, crease recovery angle, foam application

ÖZET

NANO VE KONVENSİYONEL BURUŞMAZLIK BİTİM İŞLEMİNDE İŞLEM PARAMETRELERİNİN ETKİLERİNİN KARŞILAŞTIRILMASI

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Tekstil bitim işlemleri gün geçtikçe ilerleyen teknoloji ile birlikte daha fazla kullanım alanına sahip olmuştur. Ürünlere verilmek istenen efektler bitim işlemlerinin gelişmesi ile kolaylıkla uygulanmakta ve bunun için diğer sektörlerde olduğu gibi tekstil sektöründe de nano teknoloji önem kazanmaktadır.

Nano teknoloji sadece lif yapımında değil aynı zamanda bitim işlemlerinde de kullanılmakta ve son zamanlarda küçük boyutta (nano boyutta) kimyasallar üretilmekte ve ticari olarak kullanılmaktadır.

Bu çalışmanın amacı; iki farklı boyuttaki reçine ile buruşmazlık apresini 100% pamuklu dokuma numune kumaşlara fulard ve yeni geliştirilen köpük yöntemiyle uygulamak ve bu numune kumaşlara mekanik testler uygulayarak; aşınma dayanımını, buruşma geri dönüşüm açısını, kopma mukavemetini, yırtılma mukavemetini ve spektrofotometre yardımıyla renk değişimini gözlemlemektir. Sonuçların yorumlanıp iki farklı boyuttaki reçineler arasında kıyas yapmak ve bu sonuçlara göre çok eksenli grafikler MATLAB programıyla çizilip, oluşan alanlar hesaplanıp bu hesaplamalara göre en iyi reçeteyi seçmek hedeflenmiştir ve en iyi reçete belirlenmiştir.

Anahtar kelimeler: buruşmazlık apresi, DMDHEU, parçacık büyüklüğü, pamuklu kumaş, buruşmazlık geri dönüşüm açısı, köpük aplikasyonu

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CHAPTER 1

INTRODUCTION

Textile finishing is the most important and final stage to impart high quality, good visual aspect, best touch and gain desirable properties to textile materials [1].

Cotton based textiles are always popular. The comfort to wear always enables popularity for cotton fabrics. But creasing of cloth easily causes disadvantages. Crease recovery for appearance is very important [2,3].

Crease resistant finish is used commonly in textile industry to give anti-crease property to cotton fabrics and garments. Because untreated cellulose has poor recovery, so it is necessary to apply crease resistant finish [4,5]. The creasing behavior of cotton is observed because of free hydroxyl groups in amorphous region. Cross-linking of polymer chains prevent creasing of cellulose fabrics, cross-linking prevents water to enter in the chains [4,6]. So, cellulose cross-linking is very crucial for textile chemical process and the basic application in huge textile finishing industry. Formaldehyde based N-methylol cross-linkers can enable advantages for mechanical properties such as crease resistance, anti curl, shrinkage resistance, durable press. Besides these advantages, there are some drawbacks such as strength loss, high formaldehyde release (as known human carcinogen) [4,7]. Dimethyloldihydroxyethyleneurea (DMDHEU) is the most applied durable pres agent that gives crease resistance to textile material consists of cotton or cotton blends [8].

In this study, we have applied crease resistant finish to the 100% cotton woven fabrics to impart high crease resistance and also good strength and tear resistance to the fabrics.

The basis of this study was to apply cross-linking agent with two different particle sizes to the fabric samples at same conditions. And we derived different recipes with both two cross-linking agents. The recipes include; (7) different pH values, (8) different cross-linking agent-catalyst ratios, (9) different drying-curing methods. The performance of cross-linking agents were evaluated by measuring the crease recovery angle, tensile strength, tear resistance, whiteness index value by spectrophotometer, abrasion resistance of treated fabrics. The multi-axial graphics were drawn by MATLAB, and the areas obtained between the axes were calculated with this program. We assumed that the larger the area the better the crease recovery treatment performance; hence the largest area would give us the most suitable recipe because the axes were chosen as process outputs: abrasion resistance, crease recovery angle (warp and weft), tensile strength (warp and weft), tear resistance (warp and weft), and whiteness index.

We now have opportunity to evaluate the effect of particle size of crease recovery agent along with pH value and cross-linking-catalyst ratio of the recipes.

1.1. Purpose of This Thesis

New technologies in textile finishing is crucial for researchers. Different particle size chemicals are gaining importance every passing days, indeed. The small particle size chemicals have more advantages than conventional chemicals. Despite the fact that the literature survey shows that there is almost no detailed research on this parameter.

Crease resistant finish with different particle size cross-linking agents at different pH values and with different drying-curing steps were applied to 100% woven cotton fabric samples in this experimental study. The fabric samples are seperated in two groups, after application some physical tests were done to the fabric samples;

- Tensile strength
- Tear strength
- Abrasion resistance
- Crease recovery angle
- Whiteness and yellowness indices on spectrophtometer

Chemical applications and physical tests of first group of samples were performed with the equipments and devices in in accordance with the standards of AATCC and TSE. Chemical applications of second group of samples were applied at Gaston Systems Laboratory, USA and physical tests of second group of samples were performed in Textie Engineering Department of Gaziantep University.

The main purpose of first group of samples is to evaluate the differences between results of tests done with small particle size cross-linking agent and conventional particle size cross-linking agent.

The main purpose of second group of samples is to evaluate the differences between results of tests done with padding application and foaming application.

For this study 100% woven cotton fabric was acquired and 7 different recipes (both DMDHEU and Nanolink) were applied to the fabric samples in first group. 100% woven cotton fabric was acquired and 3 different recipes (both DMDHEU and Nanolink) were applied to the fabric samples in second group. After physical tests multiaxial graphics were drawn and the area between the axes were calculated by MATLAB. The bigger area was detected and the best recipe was chosen.

1.2. Structure of Thesis

Chapter 2 is named as 'Principles of Crease Resistant Finish and Application Techniques'. The main purpose of this chapter is to give basic informations about crease resistant finish and to explain the application techniques of crease resistant finish.

Chapter 3 is named as 'Materials and Methods' includes the explanation of the apparatus and details of experimental study. Also laboratory test equipments used in the experiments are explained. This chapter is about experimental studies.

Chapter 4 is named as 'Results and Discussions'. In this chapter experimental observations and results are given. Besides results, discussions are included in this chapter.

Conclusions of this thesis and recommendations for future works take place in Chapter 5 as 'Conclusions and Recommendations'.

CHAPTER 2
THEORETICAL BASIS OF THE STUDY

In textile market, it can be seen the increase in textile finish application especially for chemical finishes that imparts the properties of textile. Finishing is defined as chemical or mechanical treatment applied to the textile material to increase the properties of textile. Crease recovery treatment is one of the most commonly applied textile finish over the years. Popularity of crease recovery treatment of textile has increased day by day.

2.1. What is Crease

Crystallites, microfibers are in balance in textile fibers, when any load is applied to the fabric, fibers can make slippage to each other by means of this load and they can form another new balance. After removal of applied load, new balance can not recover previous balance, so fibers and of course fabrics are being creased.

It's clearly seen that wrinkles can be described as fabrics distortion under any load stress [9]. The principle of crease can be seen clearly in Figure 2.1 [10].

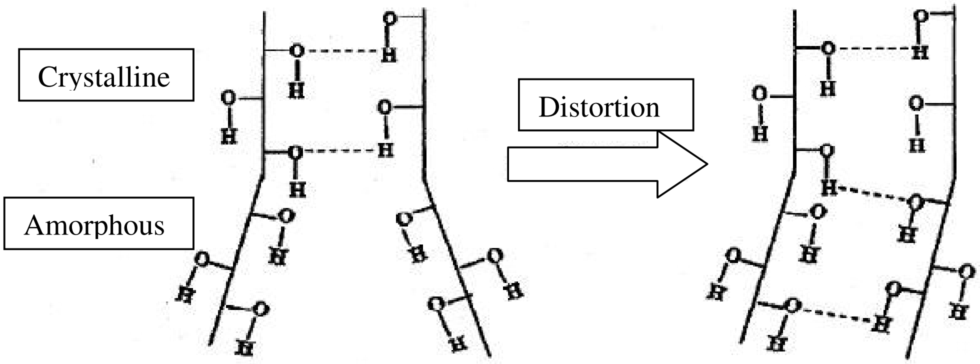


Figure 2.1 Principles of crease formation [10]

There are lots of parameters that affect the quality of woven fabric. Fast growing technologies can help the producers to generate better and more comfortable fabrics than before. So the finishing operations are much more crucial than every passing day.

Weaving type, yarn type and fiber type features become more of an issue in creasing of textile materials. Thicker and higher crimped yarns, complicated weaving reports and knitted fabrics do not set off crease so much.

There are some parameters of fibers which affect creasing phenomena;

- Orientation of fibers
- Molecular structure of fibers
- Cross-section of fibers
- Moisture effect on fibers

Orientation of fibers: High orientation causes high tensile strength, low elasticity and high creasing behavior. Figure 2.2 proves that cotton and linen tends to crease more than other fibers.

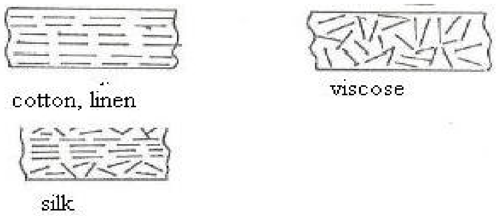


Figure 2.2 Longitudinal views of fibers [11]

Molecular structure of fibers: Cotton fiber has a straight and stiff molecular structure, wool fiber has a curly, helix molecular structure. The straight and stiff molecular structure of cotton causes non-elasticity and high creasing property. In Figure 2.3 it can be seen the difference of molecular structure of wool fiber and cotton fiber.

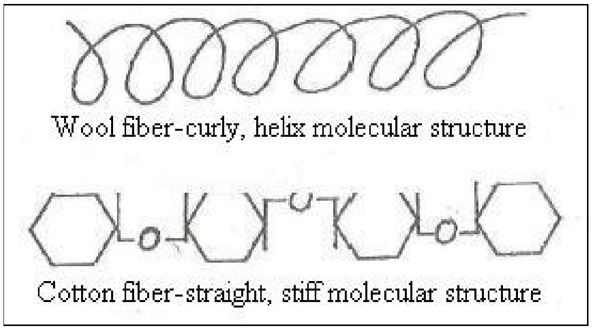


Figure 2.3 Structure views of wool fiber and cotton fiber [11]

Cross section of fibers: The fibers, have ribbon like cross section, tends to crease much more than fibers have circular cross section. There are some cross sectional views in Figure 2.4.

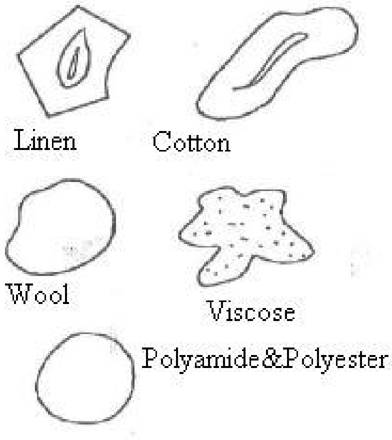


Figure 2.4 Cross sectional view of fibers [11]

Moisture effect: When fabric absorbs moisture in structure, the plasticity feature will increase. The explanation of this situation is that when water enters to the structure, H_2O molecules bond to the Valens bonds and these bonds cause to swell of fibers. After drying, shrinkage occurs. Synthetic fibers have high orientation in structure, but because of the cross section type and less moisture content, they don't show creasing case. When considering the parameters affect creasing, cellulosic fibers show creasing property much more than others. Some features can be added to textile materials after crease recovery treatment:

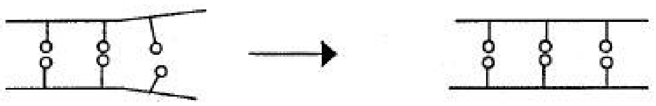
- Easy to wash
- Easy to dry
- Easy iron after drying
- Low shrinkage

100% cotton woven fabric and some other fibers similar to cotton can show creasing during drying and these creases can be eliminated by ironing. The aim of crease resistant finish is to give cellulosic fibers low creasing property and easy care. The main purpose of crease resistant finish makes form-stable, non-shrink, low pilling property textile materials [11]. Cross-linking of cellulose is an important textile chemical process and enables to the manufacturer a plentifulness of commercially important textile products [12].

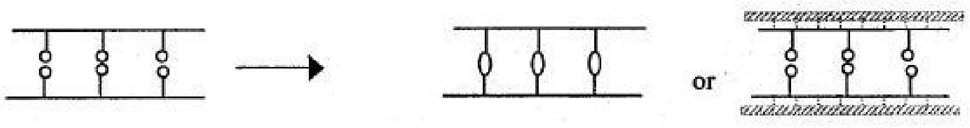
2.2. Theoretical Model of Crease Resistance

Related with principle of crease formation in Figure 2.5 shows the prohibitory mechanisms that can be taken in amorphous region to reduce crease formation conditions on cotton fabric. In Figure 2.5, the prevention of crease can be achieved by 4 different approaches.

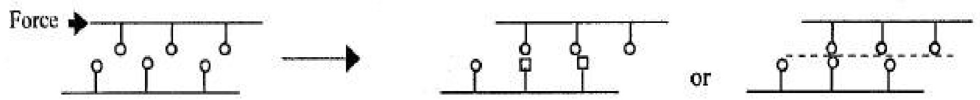
Approach (i) Improve Chain Alignment



Approach (ii) Restrict Chain Displacement



Approach (iii) Prevent New Bond Formation



Approach (iv) Restore Chain Position

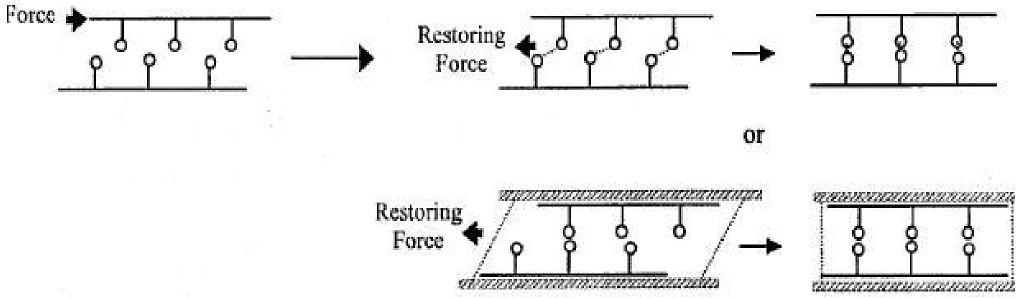


Figure 2.5 Approaches to prevent crease formation [10]

2.3. Components of Crease Resistant Finish

Three main components are listed below in Table 2.1.

Table 2.1 General recipe of monomer cross-linking system [10]

Component	**General Function**
Cross-linker	React with hydroxyl groups and impart linkage between chains
Catalyst	Initiate the cross-linking reaction
Softener	Improve handle, abrasion resistance and wrinkle resistance

2.3.1. Cellulose Cross-linkers

It's possible to divide cellulose cross-linkers in two groups, cellulose reactants which are cross-linked predominantly, aminoplasts which are cross-linked by self-polymerization. These two types consists formaldehyde reaction chemistry, so the summary of formaldehyde chemistry will show the working principle of these auxiliaries. Conventional finishes can be separated in two groups; one is reactant type other is resin type [13].

2.3.1.1. Resin Formers (Aminoplasts)

Most crucial type of formaldehyde condensates are; urea formaldehyde and melamine formaldehyde. It's possible to crosslink by itself to form resin, 3-dimensional polymers.

Urea Formaldehyde

Methylolation is caused by reaction of –N-H with HCHO to form $–NCH_2OH-$. And also this is known as N-methylol group. Urea can be used as crease resistant finish. The maximum methylolation of urea is with 4 moles of formaldehyde, when one mole of urea is reacted with 2 moles of HCHO, dimethylol formation is occurred.

$$NH_2-\overset{O}{\overset{\|}{C}}-NH_2 + 2\ CH_2O \longrightarrow HOCH_2NH-\overset{O}{\overset{\|}{C}}-NHCH_2OH$$

Figure 2.6 Formation of dimethylol urea [14]

When urea is formulated with catalyst, the finish bath should be used with a few hours due to high formaldehyde. Finish can be treated easily and imparts crease recovery property. There is a negative situation about fabric handle, after this treatment fabric becomes stiffer. Finish treated fabrics have poor durability when laundary is repeated, so crease recovery is lost due to unstable crosslinking.

Melamine Formaldehyde

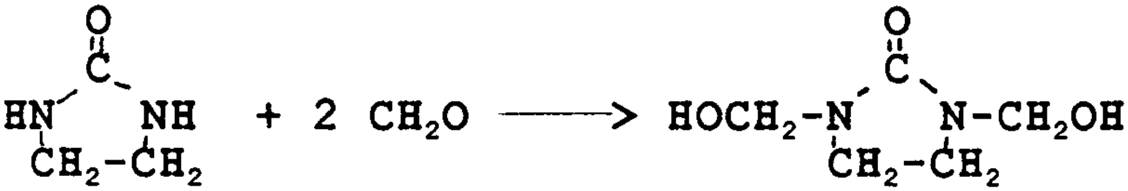
Maximum methylolation of melamine is with 6 moles of formaldehyde. The most crucial condensates of melamine are trimethylol and hexamethylol. Durability of melamine to repeated laundering is much better than urea formaldehyde. So it can be a positive feature for permanent finish. Melamine formaldehydes are used with phosphorus flame retardants, namely melamine is an excellent source of nitrogen.

2.3.1.2. Reactants

There is a difference between reactants N-methylol compounds and aminoplasts. The difference is that reactants can not form 3-dimensional polymers by themselves. By application to cellulose, reactants crosslink to adjacent polymer molecules. The most traditional are derivatives of ethylene urea, 4,5-dihydroxy-ethylene urea and hydroxyethyl carbamate.

Dimethylol Ethylene Urea (DMEU)

DMEU can be done by ethylene urea, a 5 membered heterocyclic nitrogen compound. Ethylene urea consists of 2 N-H groups that can react with formaldehyde and can make difunctional product. N-methylolated product can not self-condense due to lack of hydrogen sites.



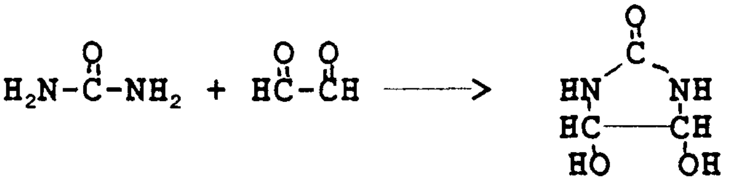
DMEU

Figure 2.7 Methylolation reaction [15]

DMEU was used in 1960s as a wash and wear finish. This product is much better than aminoplasts. And also by mixture of catalyst, life of bath is more adequate than other applications. DMEU is easily treated. The wrinkle recovery is highly efficient and the future strength is less than other finishes. Cross-links stability is not good when laundry. (Esp. Industrial laundry)

Dimethylol-4,5-Dihydroxyethylene Urea (DMDHEU)

DMDHEU is generally used in durable press finish. Some derivatives and DMDHEU are usually consumed as crease resistant chemicals. Commercially DMDHEU is known as glyoxal based resin [15]. The resin finishing manufacturers have made researches for a non-formaldehyde finishing treatment to enable safety. The general low-formaldehyde cross-linking agent is DMDHEU. These products enables long life bath and also it contains catalyst. It is better than DMEU because of better hydrolysis resistance of cellulose cross-links. So it causes durability against laundering. DMDHEU with softeners are applied to fabrics to obtain good fabric handle [14].



4,5-Dihydroxyethylene Urea

Figure 2.8 Synthesis of 4,5 - dihydroxyethylene urea [14]

Carbamates

Carbamates react with formaldehyde to obtain N-methylol derivatives. Carbamates are known as simple urethanes. But there are some problems with methyl and ethyl carbamates. They cause cancer problem for human beings. Because of this situation, these carbamates can not be used. But propyl and hydroxyethyl carbamates are safe to use.

By means of carbamates, these resins enable good durable press property and the fabrics can be cured with stronger catalyst and/or higher curing conditions. But there will be great losses in strength of fabric and abrasion resistance [15].

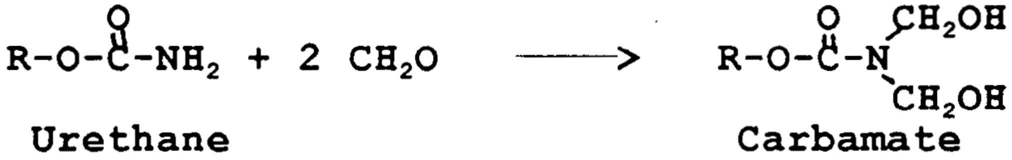


Figure 2.9 Synthesis of carbametes [15]

2.3.2. Catalyst

Cross-linkers commonly used in resin finishing are used only with catalyst. The action of these catalysts is based on freeing of hydrogen ions. Catalysis, namely acids, breaks the link between carbon and oxygen of N-methylol groups and hydroxyl groups of cellulose start to react with discharge of water.

Catalyst has three main functions;

- Provide equilibrium between the N-methylol compound and formaldehyde split off from it.
- Dispensation of formaldehyde consumed by cross-linking.
- Catalysation of cross-linking of N-methylol compounds and formaldehyde with the cellulose [16].

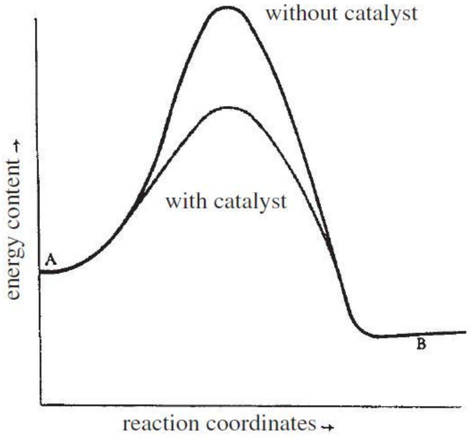


Figure 2.10 Energy profile of a catalyzed and non-catalyzed reaction [16]

It's possible to see the related catalyst-cross-linking type in Table 2.2.

Table 2.2 Common catalysts for dry, moist and wet cross-linking [16]

Type of finishing (Fiber swelling state)	Type of Catalyst	pH
Dry cross-linking (not swollen)	Metal salts, ammonium salts	3-6
Moist cross-linking (partially swollen)	Mixed catalysts, free acids	1-2,5
Wet cross-linking (swollen)	Free acid, free alkali	0-1,5 and/or 10-12

2.3.3. Softeners

Softeners are chemicals which improve fabric handle and enable best touch [15,16]. The most common softeners are detailed below;

Non-ionic softeners: These softeners have less efficient property than anionic and cationic softeners.

Anionic softeners: These softeners have good characteristic as lubricating softening agents and give fabric a full handle. These softeners don't cause yellowing at condensation temperature.

Cationic softeners: They are usually quaternary ammonium salts, amino esters and amino amides. These softeners are best softening agents.

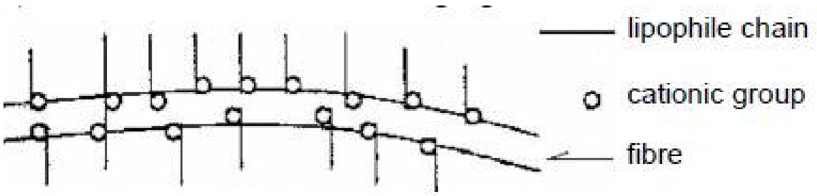


Figure 2.11 Distribution of the surfactant on the fiber

Silicone based softeners: These softeners are insoluble in water, shows good fastness to washing.

Reactive softeners: N-methylol derivatives of superior fatty amides or urea compounds replaced with fatty acids. These softeners have to be cross-linked and provide permanent softness and water repellency [15,17].

2.4. Application Techniques of Crease Resistant Finish

Textile finish industry is growing day by day. The researches are also a big part of industry and there are lots of treatments available to obtain good properties for fabrics [2,11].

The crosslinking process can be applied in three different ways: pad treatment, humid process and wet process.

2.4.1. Pad Treatment

It’s the most traditional methd applied to fabrics. The working principle is that fabric is impregnated by padding and then drying and curing. The crosslinking action is occured in stenter namely in drying section [17]. The most advantage benefit of this method is that it enables to get high springback angles for dry creases. This method is low cost, but there are some drawbacks that results are not effective and it can destroy the textile material in stenter with high temperatures. Tearing and abrasion resistance losses can be compared to dry crease angle, it is generally high [11,17].

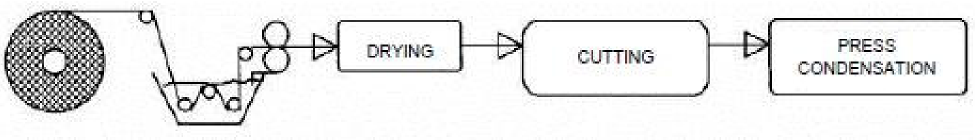


Figure 2.12 The dry permanent-press cross-linking process carried out with post-curing method [17]

2.4.2. Humid Process

The fabrics are wetted by a padding unit in a solution which contains crosslinking agent and catalyst. Then remain moisture (6-8%) is improved from cotton, after then fabric is covered with a polyethylene sheet and waited about 16-24 hours at ambient temperature. It's obvious that this process can not allow long-term processing. Fabric handle is soft and results are similar to dry crease process [17].

2.4.3. Wet Process

This process can be applied in acid or alkaline media. But application in alkaline region is not common, because of limited crease recovery. This method is also similar to humid process, the only difference is drying section. Material is wrapped, wound and covered with polyethylene and kept rotated for 16-24 hours [11,17].

2.5. Foam Technology in Textile Finishing

2.5.1. Introduction

A foam system could be the most logical alternative to the conventional pad-mangle system. The important point of foam processing is that the reagent is applied to the fabric in the form of foam in contrast to the conventional process of impregnating the fabric with a dilute solution of the reagent [18]. Air replaces water as the transport medium for the reagents, so it achives energy-saving in the drying of fabrics less waste disposal and enhanced quality of the product may be realised.

2.5.2. The Nature of Foam

Foam = Phenomenon

Foam is liquid in capsulated air. Most of contain surfactants; i.e. complex molecules aggregating at the bubble surface [19].

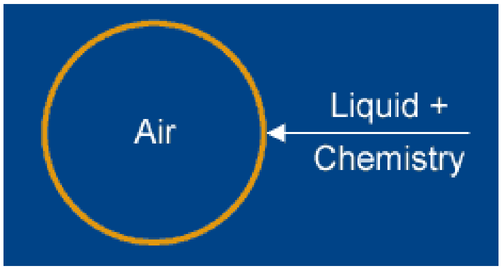


Figure 2.13 Foam bubble [19]

The foam buble is a flexing unit. Bubble rearrange constantly and flow like a liquid under enough pressure [20].

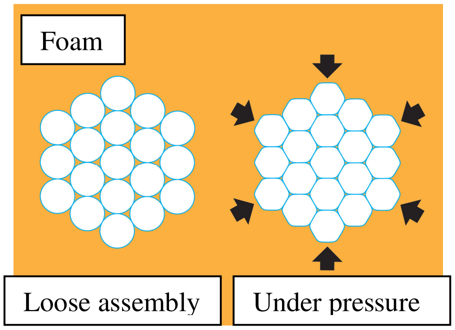


Figure 2.14 Foam bubble under pressure [20]

A varying bubble size represents an unbalanced bath density. It will never be able to produce an even chemical treatment [18].

2.5.3. Foam Characteristics

2.5.3.1. Foam Structure

Foam can be described spherical or polyhedral-shaped bubbles. *Spherical foam* is concentrated assembly or accumulation of discrete bubbles in a liquid spaced at distances greater than their diameter. Polyhedron foam is an aggregation of closely spaced polyhedral shaped bubbles, which burst almost immediately after they are formed [21].

2.5.3.2. Foam Properties

Governing Factors: Foam properties are governed to a large extent by the method of generation and by the treatment-liquor composition, with other factors, such as the purpose of which the foam is generated and the method of foam application.

Foaming degree: This is the measure of the extent of foaming. It’s an indication of the volume of foam in liters that has been produced from one liter of liquor. The foaming degree is expressed on terms of foam density (g/mL) or is known as blow ratio. Foam densities of between 0,07 and 0,14g/mL and between 0,2 and 0,33 g/mL have been used for foam finishing and foam printing [22]. Blow ratio is defined as mass of a given volume of liquid before foaming to the mass of the same volume of foam [18].

Foam Stability: Foam stability is defined as measure of the time that a foam will maintain its initial properties as generated. Foam stability is required during generation, transportation and application to the fabric and has to be lost thereafter.

Foams that are too stable are difficult to collapse, hence penetration into the fabric is poor. On the other hand, relatively unstable foams collapse before the point of application, resulting in an uneven distribution of chemicals on the fabric [23].

Foam stability can be expressed in terms of half-life, which means the time required for half of the volume of liquid contained in the foam to revert to the bulk liquid phase. The shorter the time, the lower is the stability of the foam. It's repeated that foam half-lives vary according to the type of process for which they are used; for example; 30-45 minutes for finishing, 30-180 minutes for dyeing, 8-10 hours for printing [50].

Foam Viscosity: This is the measure of foam stiffness or resistance to flow when the bubble walls are still in liquid state [18].

Foam Wetting Power: The foam has to spread out on the substrate first and then break, releasing the liquid to penetrate the fibers. The wetting power can be assessed by the spreading or penetration rate [24].

Bubble Size and Size Distribution: Bubble size and bubble size distribution are important criteria of foam behavior. Foam of finer bubble size is more stable then foam of the same density with coarser bubbles [18].

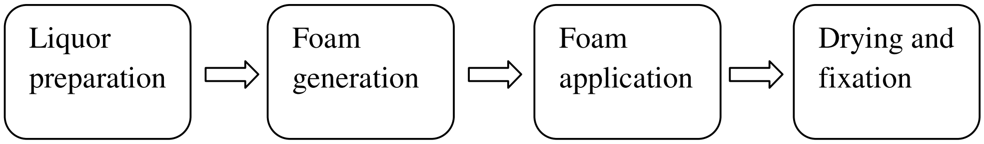


Figure 2.15 Block diagram of foam sequence of processing

2.5.4. Foam Application

2.5.4.1. Conventional Pad System

Conventional pad system is tailing. It has limited speed and high chemical cost. And besides that it's different to make this system flexible. (Fig. 2.16-a)

2.5.4.2. Vacuum Slot

Vacuum slot system is used rarely because it has high power requirement and limited moisture extraction. (Fig. 2.16-b)

2.5.4.3. Spray Method

Foam application by spraying is unreliable, because it can not be controlled, on the other hand the speed of this system is limited. (Fig. 2.16-c)

2.5.4.4. Kiss Rolls

The surface of fabric has immensely chemical agents by this system. Like other conventional systems, the speed of treatment is limited. (Fig. 2.16-d)

2.5.4.5. Curved Blade Applicator

Similar to kiss rolls, in this system the chemical agents are on the surface totally. This device is not a direct metering type. (Fig. 2.16-e)

2.5.4.6. Knife Coater

Knife coater is specialized on fabric type. The speed and viscosity depend on the fabric type. (Fig. 2.16-f)

2.5.4.7. Curtain Coater

Curtain coater is not common. The biggest disadvantage of this system is that it is unsuitable for low add-on rates. (Fig. 2.16-g)

2.5.4.8. Engraved Roller

Engraved roller system is similar to kiss rolls, the unique difference is roller type. The drawbacks are that the speed of system is limited and the add-on is inflexible. (Fig. 2.16-h)

2.5.4.9. Flooded Nip

The transfer of foam is achieved as the carrier and the fabric come into contrast. Drawbacks are similar to others; the speed of system is limited. By this system the chemical usage is too high and on the other hand it's inflexible (Fig. 2.16-i) [18,20].

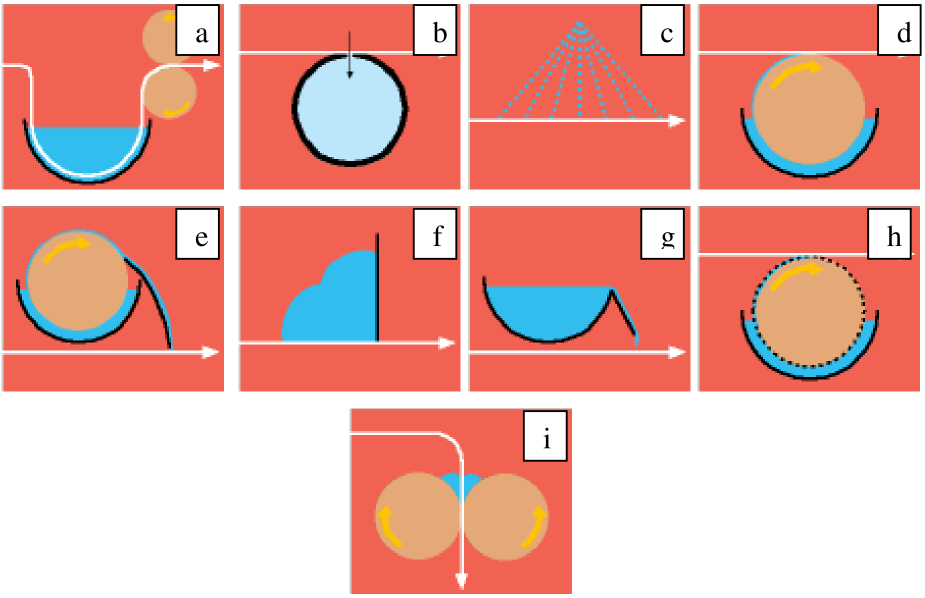


Figure 2.16 Different types of foam application

2.5.4.10. Chemical Foam System

Chemical foam system (CFS) is unique in its ability to place chemicals into or onto substrates in a controlled manner. It offers so many benefits that many consider CFS technology to be the future of chemical application to open-width substrates.

Foam application to woven and knitted fabrics and nonwoven substrates from a pressure plenum was developed in the early 1970s. The principle objective was to provide finite control over chemical application relative to uniform quality and controlled penetration. Foam was chosen as the preferred medium because it extends the surface area of the chemical to more closely match the surface area of the fibers while greatly water use.

The substantial water reduction eliminated the problem of cross-sectional chemical non-uniformity due to migration. It also produced significant cost savings due to reduced energy requirements for drying operations. Typical wet pickups vary from 3% to 50% on weight of dry substrates [20]. Figure 2.17 compares CFS application to fabrics for a range of fiber blends.

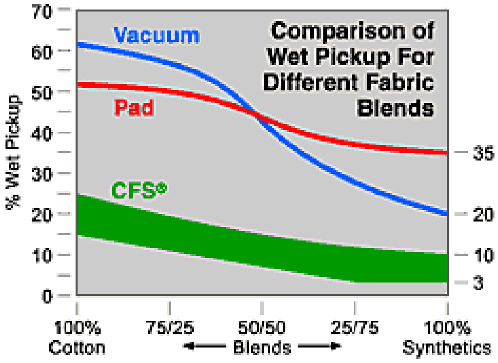


Figure 2.17 Comparison of wet pickup for different fabric blends [19]

The first commercial units, designed for application to textile piece goods, were installed in 1979. Since then, the technology has evolved and has been introduced int the nonwoven, paper, and carpet trades. Further, it has been found to be beneficial for coating operations as well as wetting out yarns in a controlled manner. Today, hundreds of CFS systems are operating throughout the world, applying a wide variety of chemicals, binders, dyes, finishes etc. [19,20].

2.5.4.10.1 Benefits and Characteristics

The technology of applying foam under pressure has several unique characteristics and important advantages:

- High concentrations of chemicals applied.
- Minimum need for thickeners.
- Precise and controlled liquid feed rates.
- Controlled, uniform and repeatable foam bubble size.
- Wide range in foam densities.
- Significant reductions in water and energy consumption.
- Flexibility in chemical applications.
- Measurable reductions in waste volumes with zero discharge possibilities.
- Reduced air pollution.
- Fast wetting and penetration rate into substrate.
- System speeds go as high as 1000 meters per minute in some specific applications.

2.5.4.10.2. The Difference Between CFS and Other Foam Applicators

Foam which is expected to treat fabric uniformly in a flooded nip arrangement, will not be controllable and produces inferior results. Foam must be confined to do the expected work in a repeatable manner. With CFS, foam is under pressure and highly controlled.(Figure 2.18)

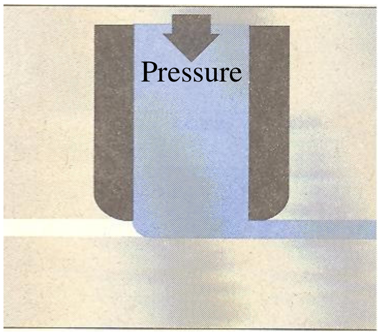


Figure 2.18 CFS foam application under pressure

Foam is used only as a convenient chemical delivery mechanism of the chemicals involved. The average life expectancy of the foam application is associated with a very temporary physical state of the chemical solution.

2.5.4.10.3. Unique Versatility and Economics Enhances Role of Chemical Application

At today’s level of understanding and experience, it can be said that chemicals of all categories are foamable in some form. Some of the chemical categories used in foam application are listed below.

Resins

- Glyoxals
- Melamine formaldehyde
- Urea formaldehyde

Weighters/Binders

- Polyvinyl acetate
- Polyvinyl alcohol
- Polyacrylic acid
- Modified starch

- **Softeners and Lubricants**
- Cationic
- Nonionic
- Polyethylene enclusions
- Nonionic silicones

Functional products

- Soil repellants
- Oil repellants
- Water repellants
- Stain repellants
- Fluoro chemicals
- Pigments and dyes
- Anti-slip coatings

Some of the areas of application are listed below:

- Agriculture
- Apparel (woven, knitted)
- Automative
- Abrasives/polishing
- Building/constructions
- Containers/packaging
- Disposable absorbents
- Filtration
- Geotextile/civil engineering
- Home furnishing
- Medical/healthcare
- Nonwoven in general

Because of its unique properties, CFS is the most versatile system for applying chemicals to open-width substrates available. This versatility gives manufacturers and convertors another tool for reacting to changing market demands.

Figure 2.19 shows an example of new possibilities. When combined with the fact that CFS uses the absolute minimum amount of water and can provide top quality at very high range speeds, the economics and performance of CFS application make it very attractive indeed.

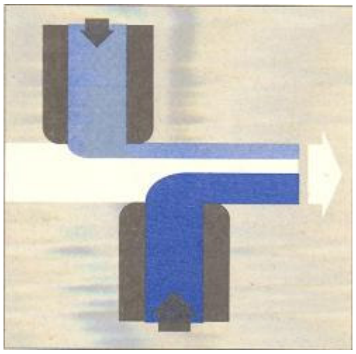


Figure 2.19 CFS with different chemicals and different depths

2.5.4.10.4. Total System Approach

It's also relevant to consider foam application equipment not only in terms of producing foam by a foam generator, but equally significant, as it applies to the applicator.

Just as important as the equipment is the proper chemistry. Experience has shown that the best results are achieved when the foam generator, foam applicator and chemical mix constitute one entire system. Figure 2.20 shows a schematic of the CFS system.

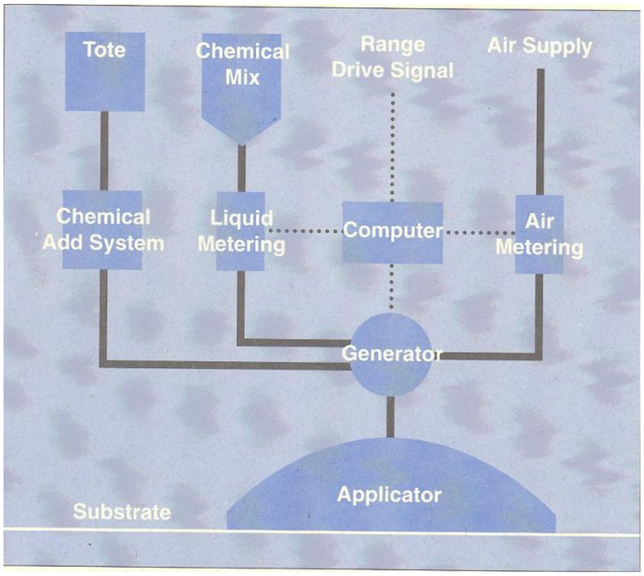


Figure 2.20 Schematic of the CFS technology

2.5.4.10.5. Economic Benefits

Good economics are the result of payback conditions initiated by several different factors. Some of these factors have a greater impact than others because of the cost and value attached to each. Costs for waste, power, floor space, waste water treatment, air pollution, labor costs, chemical costs, better quality assurance, and market demands are all common factors, each of which can vary widely from one region to another.

In general, economic incentives to invest in CFS come from:

- Reduction in water consumption: up to 80%
- Reduction in energy use: depends on reduction of evaporation loads
- Reduction in chemical costs: results from precise chemical placement
- Range speed increases: the consequence of reduced wet pickups
- Better quality control: reduced seconds
- Greater application flexibility: producing higher margin specialty fabrics
- Range speed tracking, 80 standard programs, actual repeatability of applications [18-20].

2.6. Nanotechnology in textile industry

2.6.1. What is nano

Nano – (symbol n) is a prefix in the metric system denoting a factor of 10^{-9} or 0.000000001 [25]. One nanometer is one billionth meters that is about 100.000 times smaler than diameter of a single human hair [26].

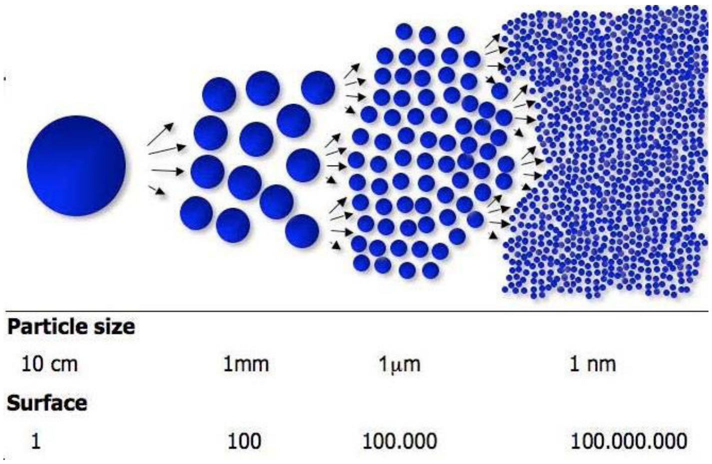


Figure 2.21 Schematic representation of particle size and surface [27]

2.6.2. Nanotechnology

Conjunction with 21th century, nanotechnology is becoming one of the most important step for each industries [10]. Nanotechnology is a crucial interdisciplinary field deals with structural material on the level of industrial atoms and molecules [28]. Nano particles commonly used in commercial products are in range of 1 to 100 nm [29].

2.6.3. Nanotechnology in Textile

Nanotechnology has already replaced in textile industry [26,29]. The main reason of nanotechnology in textile industry is that conventional methods used to give desirable properties to fabrics, but generally conventional methods can not be permanent on fabric, and fabrics will loose the properties by every laundering or wearing [29]. Nanotechnology can take part in textile industry to obtain fabric softness, durability, breathability namely water repellnecy, fire reterdancy, antimicrobial and crease resistance in fibers, yarns and fabrics [30]. Current applications of nanotechnology in textile industry are in fibers, yarns, nonwovens, dyeing, finishing and coating applications [31].

Applications in fibers: In technical applicaitons, fiber based materials take part in a big area [32]. The researches have been continued for 20 years and especially US Army Natizik Soldier Center has made researches to produce barrier fabrics made from nano fibers [33].

Applications in woven and knitted fabrics: This application is generally related with medical textiles such as woven and knitted artificial vascular grafts [31].

Applicaitons in dyeing process: Nanotechnology has an important role for dyeing process. The nanoclay, montmorillonite and some modified nanoclays can be used as an absorbent for nonionic, anionic and cationic dyes. Due to absorption; dyeability, color fastness increases however dyeing costs decreases [31].

Applications in textile finishing: New application techniques can be treated to the fabrics by growing nanotechnology in textile finishing area. Nanotechnology not only exist in making fibers or composites but also in making chemical finishes [26]. Coating is general application method in textile finishing with nanotechnology [29,31]. There are several methods to apply coating on textile; spraying, transfer printing, rinsing and padding. Padding is the most common technique among them

[29]. Nanoparticles such as metal oxides or ceramics also take place in textile finishing to obtain desired properties. When nano size particles compared with large size particles, they have a larger surface area and it causes high penetration and more efficiency [26]. If the Figure 2.22 is examined, nanoparticles are applied to textile substrate [10]. It's easy to control nanoparticles when compared with conventional particles of chemicals [34].

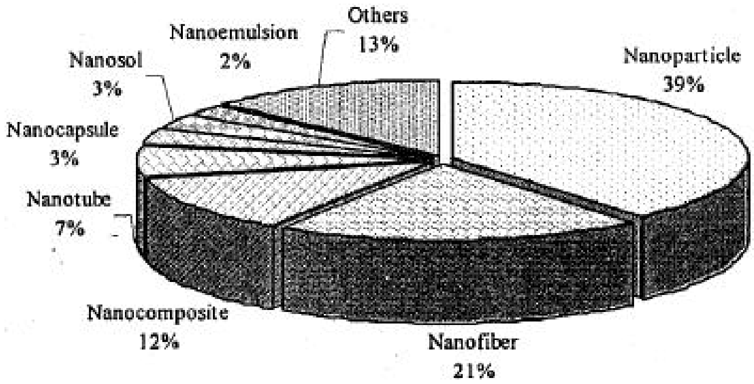


Figure 2.22 Types of nano particles commonly found in textile application from 1995 to 2005 [10]

Table 2.3 The distribution of nano material application [10]

Application	**%**
Multi-functional	16,9
Antibacterial	12,0
Dyeability	11,2
Environmental Protection	7,0
UV blocking	6,2
Antistatic	5,8
Conductive	5,0
Flame Retardant	3,7
Protective	3,7
Strength Improvement	3,3
Water Repellent	3,3
Thermal Property	2,5
Additives/Catalyst	2,1
Dirt/Soil/Repellent/Self Cleaning	2,1
Breathable Material	1,7
Far Infrared/Health	1,7
Handle	1,7
Wrinkle-Resistant	1,2

The textile field is applied by nano materials are summarized in Table 2.3 .[10]

Use of nano capsules are another different technique and insect repellent, anti-bacteria capsule are general examples of this technology [10].

Commonly, to impart wrinkle resistance to fabric, resin is used in conventional methods [29]. Wrinkle resistance nano size finish product is commercially available in textile chemical market and there are numerous articles have been published [10].

Nano titanium dioxide used with carboxylic acid as a catalyst in perivous research [35]. And in another research nano-silica was applied with maleic anhydrid as a catalyst to improve wrinkle resistance of silk [29].

2.7. Literature review

When the previous studies were examined, there are different studies related with crease recovery treatment or different textile finish processes.

Shet and Yabani oxidized cotton fabrics with nitrogen dioxide and sodium periodate and crosslinked with both DMU (dimethylol urea) and DMDHEU (dimethylol dihydroxy ethylene urea) by pad-dry-cure method. Pre and post oxidation affected to resin treatment on crease resistance and tensile properties were investigated. With this application, crease recovery angle increased with degree of oxidation and periodote oxidation caused release of strain in structure of cotton fabrics. However it caused losses in tensile strength. This resin treatment also imparted alkali sensitivity of periodate oxycellulose [36].

Wright studied about low wet pick up with foam application and kiss-roll method. The cotton and cotton blend fabric samples were treated with these two methods. The prime drawback was color difference. Also he explained the economic considerations of foam application method [37].

Hebeish and Ibrahim studied different catalyst type for easy care finishes. Urea nitrate was investigated to catalyze crosslinking of cotton cellulose with N-methylol finishing agents. The results showed that urea nitrate was an effective catalyst to impart easy care properties to cotton with pad-dry cure, pad-cure and pad mild-cure methods. This catalyst achieved high crease recovery angle without high losses in strength property [38].

Abhyankar et al. studied the utility of alkaline hydroliss as a method for removal of DMDHEU crosslinks from cotton . The method was carried out to fabric treated with

DMDHEU/ $MgCl_2$ and DMDHEU/ $MgCl_2$/Citric acid mixed catalyst system. Removal of the finish was completed as verified by nitrogen and formaldehyde analyses and by crease recovery measurements. The DMDHEU/ $MgCl_2$ application reduced degree of polymerization by viscosity of cotton about 24% and DMDHEU/mixed catalyst treatment reduced polymerization about 18%. This study showed the effect of catalyst on the crease recovery finish [39].

Gonzales and Reinhardt studied a fractional factorial design of cotton printcloth fabric samples with formaldehyde. HCHO with $Zn(NO_3)_2$ were applied by foam application as catalysis about 40% wet pickups. The results showed decreases in strength and abrasion performance, but the resilience was satisfied [40].

Namboodri and Duke studied with foam application in textile finishing and dyeing processes. They performed foam application techniques to get results related with energy saving and line speeds. By means of their study, they obtained 70-80% energy savings and line speed have been doubled. And also they make some applications for durable-press finish, shrinkage control on cotton and cotton/polyester fabric samples. And they obtained good results [41].

In other study, Yang was dealed with the effect of pH on anhydryd intermediate formed in a cotton fabric increases as the finish bath pH decreases from 4.5 to 1.5 [42].

Chai and Kim studied on performance of sodium perborate (SP) and borax (BO) on wrinkle recovery angle. SP and BO showed the positive same result about whitness index (WI) of cotton treated with dialdehydes, but wrinkle recovery angle decreased by increasing WI. WRA reduction can be decreased by adding formic acid (FA) into SP and BO. These results indicated that SP and BO additives along with FA can be mixed to get better performance properties of cotton treated with dialdehyde for non-formaldehyde wrinkle resistant finish than SP and BO additives used alone [43].

Hashem at al. studied on reactions of cellulose with materials that give an ionic character to the cellulose, chloroacetic acid (CAA) or 3-chloro-2-hydroxypropyle trimethyl ammonium chloride (CHTAC), which produces ionic cellulose that can sorb a polyelectrolyte of opposite charge to form crosslinks. Cationized chitosan shows significant increases in crease recovery angle without strength loss, CHTAC or CAA treated fabrics show improved crease recovery angle, generally with strength gain [7].

Wang et al. studied mixture of DMDHEU with alpha amino acids (aspartic acid and glutanic acid) as crosslinking agent and by means of this mixture, crease recovery angle situation; DMDHEU/ glutanic acid > DMDHEU/ aspartic acid > DMDHEU alone at a given tensile strength retention [44].

Udomkichdecha at al. examined to get results of unsaturated acrylic and maleic acids to impart durable press performance of cotton fabric. Both acids were copolymerized with potassium persulfate and sodium hypophosphite monohydrate used as catalyst. Operation was padding and curing. Results showed that at certain conditions, copolymer finishing agent provided good wrinkle resistance when compared with DMDHEU treated cotton fabric. But the tensile strength and whiteness index parameters were worser than DMDHEU treatment [45].

Mortazavi and Boukany was related with a mixture of DMDHEU, PVAc and some other resins were examined in special finishing of cotton for producing interlining cotton fabric properties. Crease recovery angle decreased with increasing PVAc concentration and on the contrary increasing DMDHEU concentration improved the crease recovery angle [14].

Another study Mostafa and Morsy was studied to give easy care properties to cotton fabrics with preventing the strength loss during finishing processes with tailored modified starch products. Carboxymethylated starches (CMS) and poly (acrylic acid) –grafted starch copolymers (PAGS) prepared from three levels of hydrolized starches (H1-H2 and H3-starch) having different degree of hydrolysis and three levels of oxidized starches (O1-O2 and O3- starch) having different degree of oxidation were synthesized. Results can be seperated (1) nitrogen content, crease recovery angles and tensile strength of cotton fabric finished in presence of these modified starches increases by increasing extents of either hydrolysis or oxidation of parent starch, (2) increasing the concentration of modified starches from 5 to 50 g/L in finishing bath with an increment in nitrogen content and tensile strength while crease recovery angles decrease, (3) increase in nitrogen content and tensile strength of the finished fabrics; carboxymethylated starches > poly (AA) grafted starches > hydrolized starch, (4) fabric samples treated with straches derived from hydolized starches get higher nitrogen content, crease recovery angles and tensile strength than oxidized starches [46].

Hauser et al. studied a similar topic to our work. They studied various crosslinking agents based on different chemistry in finishing of cotton fabric samples. They used Saralink ULF, Saralink 545, Natrium NFO, Macrobounce, Sarapeach AM, Sarafinish OST, Saralube HP. For best crease recovery angle and handle, Sarafinish OST has a well balanced formulation, and also it contains ultra low formaldehyde [12].

In another previous work; Bilgen developed some methods of forming ionic crosslinks to impart non-wrinkle effects on cellulosic fabrics. These methods; (1) treatment of cellulose with an anionic material and reacting with a polycation, (2) treatment of cellulose with a cationic material and application of a polyanion, (3) treatment of cellulose with a polyelectrolyte of opposite charge. The results showed that crease recovery angle and strength increases with these three methods [13].

Cai and Sun studied that durable antimicrobial acrilan fabrics were treated with cetylpyridinium chloride (CPC) in a chemical finishing process. There are some parameters affect antimicrobial properties, such as pH, temperature etc. And also pH affects mechanical properties and colour of fabrics, especially under alkaline conditions. Although a more alkaline condition is preferred for durable antimicrobial functions, high pH reduces tensile strength and reults in yellowing of acrilan fibers [47].

Jeong et al. studied a topic was related with antibacterial properties of compounded polymer/silver fibers. They compounded polypropylene with either micro or nano sized silver powders. The mechanical properties of these materials were measured and silver nano particles showed more superior antibacterial activity than sample containing micron-sized particles [48].

Huang et al. studied the effect of mixed solution on the physical properties of a treated fabric with SiO_2 and DMDHEU. DMDHEU was applied to cotton fabric and different mole ratios of tetra ethoxysilane (TEOS)/ titanium, n-butoxide (TTB) were added. Then padding, drying, curing were performed. Trated fabric improved anti crease and tensile strength retention and yellowing degree when TEOS was increased. By contrast, softness of fabric was decreased [49].

In another study, Yuen et al. perfomed to prevent cotton wrinkling. The study was occured with application of 1,2,3,4-butane tetra carboxylic acid (BTCA) which provides wrinkle- resistant similar to DMDHEU. DMDHEU has some drawbacks like free formaldehyde. In this study nano TiO_2 was used as catalyst. The addition of nano TiO_2 in BTAC treatment caused stiffer and softer handle. But on the other hand it caused decrease in tearing and tensile strength of cotton fibers [15].

Huang et al. were studied the usage of low-molecular-weight chitosan (LWCS) for anti crease treatment of cotton fabric. LWCS was prepared with DMDHEU as a crease resistant finish agent. The results were ; tensile strength retention and creasing resistance of fabrics were increased. Besides these results; yellowing index and softness of treated fabrics were increased by increasing of chitosan and curing temperature [50].

Can et al. studied about desizing, scoruing and crease resistant finish on 100% cotton fabric and effects were observed. A statistical analysis using a paired t-test with significance level of $\alpha=0.05$ had been performed to obtain statistical differences. Wrinkle recovery angle increased approximately 50%, breaking strength and tear strength decreased about 25% and pilling reduced 59% after crease resistance [9].

Güneşoğlu studied on colour differences after textile finishing processes on fabrics. He used both fluorocarbon and DMDHEU as crosslinking agents with different particle sizes. Results were indicated that small particle size chemicals caused less colour differences than bigger ones. But colour difference due to abrasion could not been affected by particle size [51].

Parvinzadeh and Hajiraissi studied about different particle size of softener on polyester fabric samples. Polyester fabric samples were treated with different three (10,20 and 30 g/L) concentrations of macro and microemulsion silicones by padding method. The drapability of fabric was lower and it depended on particle size of silicone. Crease recovery angle measurement showed that microemulsion softeners caused high recovery angle. The smaller particle size, the larger crease recovery angle value [52].

And in another study, Sahin et al. prepared anionic cotton fabric and treated with a novel crosslinking agent, namely cationic glycerin. They could get good results such as high wrinkle recovery angle and strength of fabric also increased by means of this study [4].

Hashem et al. studied to impart both wrinkle recovery and softness properties of cotton fabrics and besides non-effect to strength properties by using eco-friendly finishing agents. Firstly, pretreatment with carboxymethylation (CMC) or ionic-crosslinking and post-treatment with amino functional silicone softener. The results that post-treatment with amino based silicone micro emulsion (SiE) up to 30 g/L at pH 4 to a wet pick up 100% with drying at 100 °C about 5 minutes and curing 170 °C for 3 minutes improved crease recovery angle and softness without strength retention [53].

Fouda et al. studied on a new microwave curing system to measure the effect of crosslinking of cotton fabric with non formaldehyde finishes; glyoxal, glutaraldehyde and 1,2,3,4 butanetetracarboxylic acid (BTAC). This mixture was used to impart antibacterial activity. It was indicated that glyoxal was best finish, besides crease recovery and strength porperties of finished fabric, N%, antibacterial activity were also compared. When conventinal curing system and microwave curing system were compared, microwave curing system had advantages for easy care antibacterial property with low losses in strength [54].

Hebeish et al. studied post and pre crosslinking of cotton fabrics with cellulase enzyme. They used four different types of cotton based fabrics and fabrics were bioscoured and bleached firstly. There were an enzymatic treatment with using cellulase enzyme to affect bio polishing followed by crosslinking using N,N-dimethylol 4,5-dihydroxyethylene urea (DMDHEU) to affect easy care finishing. At result; post crosslinking and pre crosslinking showed differences in N%, wrinkle recovery angle and whiteness index. Post crosslinking caused high losses in strength properties when compared with pre crosslinking [55].

Ramachandran et al. studied with citric acid, which is a non-formaldehyde based crosslinking agent, for cotton finishing to obtain optimum results. They used Box and Behnken method, it means that citric acid was used as a crosslinking agent, trisodiumcitrate was used as catalyst and curing temperature. By hepl of the tests, the optimum results were obtained namely; 20% citric acid, 6% trisodiumcitrate and 180 °C curing temperature. And high concentration of citric acid caused increasing crease recovery angle and reducing tensile strength of cotton fabric [6].

Chattopadhyay and Vyas studied a topic similar to Parvinzadeh and Hajiroissi [52]. They investigated the nano emulsion silicone softener effect versus to conventional emulsion softener on cotton fabric. Nano emulsion softener improved handle and crease recovery angle when compared with conventional type softener. But the drawback was similar to others; high losses in strength with increased elongation at break [56].

CHAPTER 3
MATERIALS AND METHODS

In this study two different fabric type and two different chemical application methods were chosen;

1. Woven cotton fabric 100% kindly supplied by Kardesler Boya, Gaziantep, Turkey (for pad application)
2. Woven cotton fabric 100% kindly supplied by Gaston Systems Laboratory, North Carolina, USA (both pad and foam application)

The first experimental set up was organized at Textile Engineering Department of the engineering Faculty in Gaziantep University. Experiments reported in this part have all done at Gaziantep University.

The materials, equipments and experimental procedures used in this thesis are described in this section.

3.1. Materials

The test materials and chemicals that used in this study are given in the table below including names, brief descriptions and manufacturers.

Table 3.1 Test materials and chemicals for first group of samples

Name or group	Description	Manufacturer
Cotton fabric	%100 cotton plain fabric (45 x 23 warp sett x weft sett , 220 g/m^2)	Kardesler Boya, Gaziantep, Turkey
Conventional Crosslinking agent	Rucon Fan N-methylol dihydroxyethylene	Rudolf Duraner
Nano-Link Crosslinking agent	Ruco Nanolink Com 4813	Rudolf Duraner
Magnesium chloride as catalyst	Magnesium chloride hexahydrate, 99% MgCl2	MERCK 1.05833.1000
Macro silicone as softener	For pad process ph value 5-6	Rudolf Duraner MEC 900
Sodium hydroxide	pH value= 14, total alkalinity= 98-100.5 %	MERCK TK 170510.01000
Hydrogen chloride	30% (m/m), max 0,1% H_2SO_4, 0,5 ppm H_2SO_4	AK-KIMYA

Table 3.2 Test materials and chemicals for second group of samples

Name or group	Description	Manufacturer
Cotton fabric	%100 cotton plain fabric (50 x 24 warp sett x weft sett , 250 g/m^2)	Gaston Systems Laboratory, North Carolina, USA
Conventional Crosslinking agent	Rucon Fan N-methylol dihydroxyethylene	Rudolf Duraner
Nano-Link Crosslinking agent	Ruco Nanolink Com 4813	Rudolf Duraner
Magnesium chloride as catalyst	Magnesium chloride hexahydrate, 99% MgCl2	MERCK 1.05833.1000
Macro silicone as softener	Can be used either in pad or exhaust processes. For pad process ph value 5-6.	Rudolf Duraner MEC 900
Sodium hydroxide	Caustic 50% 1310-73-2	Unichem Corporation
Surfactant	Unifroth 0857-A	Unichem Corporation

3.1.1 The Particle Size Measurement

Figure 3.1 shows the multimodal size distribution analyses of the DMDHEU reagents that are used to calculate the effective diameter (Deff). Deff is the diameter that a sphere would have to diffuse at the same rate as the particle being measured and may result from one or more populations of the particles present in the emulsions. If the system is polydisperse, Deff is an average diameter, and if weighted by intensity, it is an averaged intensity of scattered light by each particle. From the multimodal size distribution, it appeared that in the investigated DMDHEU reagents nano-marked and conventional crosslinking agents (NK and K respectively), there was one remarkable population of particles arising major fluctuation; and the fluctuation of K corresponded to larger diameters than that of NK; thus Deff was measured to be 739.6 nm for NK and 851.8 nm for K. The polydispersity values for NK and K were 0.315 and 0.319 respectively, which means that emulsions prepared had similar distributions.

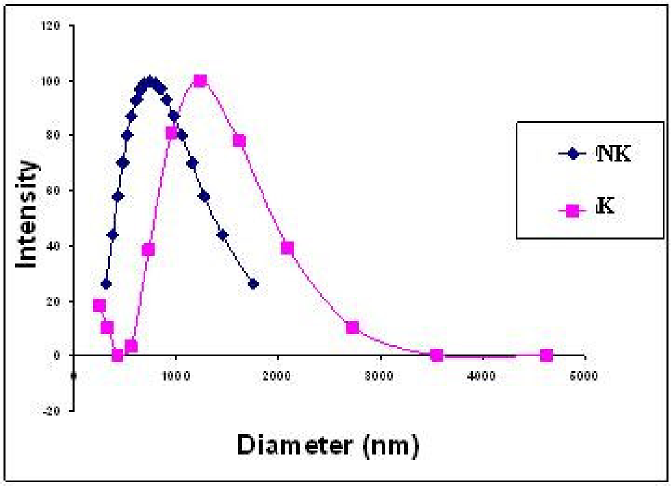


Figure 3.1 Multimodal size distributions of DMDHEU reagents.

3.1.2 The FTIR Spectrum

FTIR analyses of the DMDHEU reagents are shown in Figure 3.2. The IR spectra for both DMDHEU reagents showed also the characteristic peaks of O-H stretching (around 3300 cm^{-1}), C=O stretching (around 1700 cm^{-1}) and C-N stretching (around 1380 cm^{-1}), C-H bending (around 1236 cm^{-1}) and C-O stretching (around 1020 cm^{-1}) (Fig 5.2). The chemical compositions of the reagents were concluded as similar;

however the peak strengths were different for O-H and C-O adsorptions representing the difference in the number of glyoxals within reagent structure.

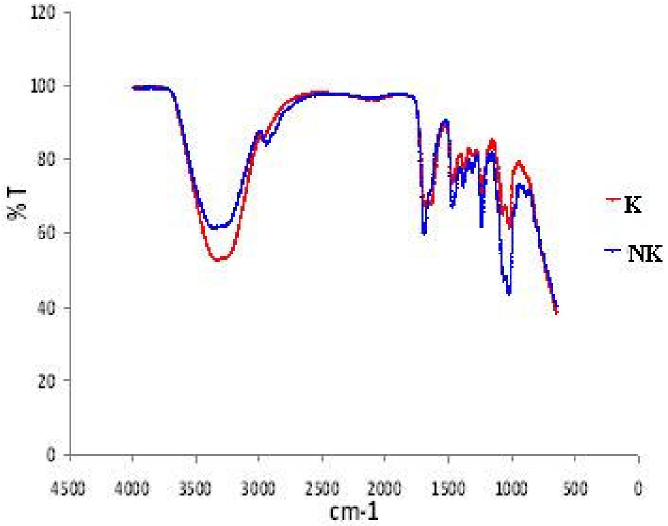


Figure 3.2 FTIR spectrum of DMDHEU reagents

3.1.3 The First Group of Samples

100 % woven cotton fabrics were woven and pretreated by Kardeşler Örgü, Boya & Konfeksiyon A.Ş. in Gaziantep. The fabric samples were prepared of 30 cm X 40 cm for crease recovery treatment pad application. All 30 cm X 40 cm fabric sample sheets were treated with 7 different recipes (recipes for both conventional and nano marking crosslinking agent) and with different drying-curing techniques by padding application.

Recipes were prepared both with conventional and nano marked crosslinking agents.

Table 3.3 Recipes belong to first group of samples

Recipes	Codes	DMDHEU (g/L)	Softener (g/L)	Catalyst (g/L)	pH	Drying	Curing
Recipe 1a	K1	40	20	10	4.5-5	130° 4 min.	170° 70 sec.
Recipe 1b	K2	40	20	10	4.5-5	175° 75 sec.	Drying & curing together
Recipe 2	K1-1	40	20	40	4.5-5	130° 4 min.	170° 70 sec.
Recipe 3	K1-8	40	20	5	4.5-5	130° 4 min.	170° 70 sec.
Recipe 4	K1 pH 2	40	20	10	2	130° 4 min.	170° 70 sec.
Recipe 5	K1 pH 11	40	20	10	11	130° 4 min.	170° 70 sec.
Recipe 6	K1 pH 8	40	20	10	8	130° 4 min.	170° 70 sec.
Recipe 7	K3 pH 2	40	20	10	2	100° 5 min.	Cured by stretch film about 72 hours in lab.cond.

Recipes	Codes	Nanolink (g/L)	Softener (g/L)	Catalyst (g/L)	pH	Drying	Curing
Recipe 1a nano	NK1	40	20	10	4.5-5	130° 4 min.	170° 70 sec.
Recipe 1b nano	NK2	40	20	10	4.5-5	175° 75 sec.	Drying & curing together
Recipe 2 nano	NK1-1	40	20	40	4.5-5	130° 4 min.	170° 70 sec.
Recipe 3 nano	NK1-8	40	20	5	4.5-5	130° 4 min.	170° 70 sec.
Recipe 4 nano	NK1 pH 2	40	20	10	2	130° 4 min.	170° 70 sec.
Recipe 5 nano	NK1 pH 11	40	20	10	11	130° 4 min.	170° 70 sec.
Recipe 6 nano	NK1 pH 8	40	20	10	8	130° 4 min.	170° 70 sec.
Recipe 7 nano	NK3 pH 2	40	20	10	2	100° 5 min.	Cured by stretch film about 72 hours in lab.cond.

Application of crease resistant finish was performed using a laboratory type padding machine manufactured by Prowhite Testing Equipments with a model no: PDF01-A/0601001 with 220 VAc 50/60 Hz. (Fig. 3.3) [57].

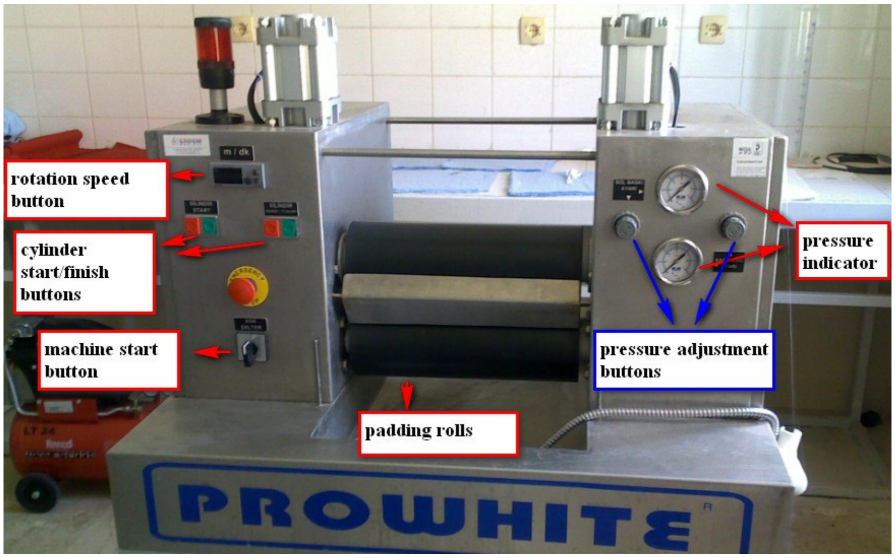
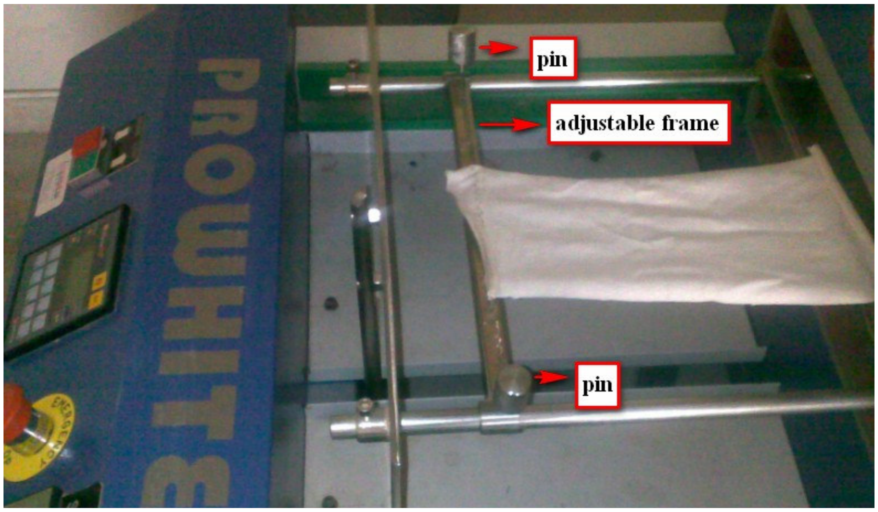


Figure 3.3 Prowhite testing equipment

The padding machine was adjusted for required wet pick up ratio about 90%. The 90% wet pick up was acquired with the pressure of cylinders 4.5 bar and time of passing fabric about 2 m/min.

After padding operation, the fabric samples were dried and cured with different drying-curing processes with laboratory type dyeing-curing machine manufactured by Prowhite Testing Equipments. This equipment is used for drying and fixation after finishing or dyeing (Figure 3.4).



To fix the fabric samples, there are pins and adjustable frames.

The drying operation can be done at desired time and temperature.

Figure 3.4 Prowhite testing equipment adjustments

3.1.4. The Second Group of the Samples

100 % woven cotton fabrics were taken and were prepared for testing from Gaston Systems, North Carolina, USA. The fabric samples were prepared about 50 cm width beam for crease recovery treatment pad and foam application. The fabric sample sheets were treated with 3 different recipes (recipes for both conventional and nano marking crosslinking agent) by pad and foam application. Recipes were prepared both with conventional (DMDHEU) and nano marked (Nano link) crosslinking agent.

Table 3.4 Recipes belong to second group of samples

Recipes	Crosslinking agent(g/L)	Softener (g/L)	Catalyst (g/L)	pH	Drying	Curing
Recipe 1a	40	20	10	4.5-5	130° 5 min.	170° 70 sec.
Recipe 4	40	20	10	2	130° 5 min.	170° 70 sec.
Recipe 5	40	20	10	11	130° 5 min.	170° 70 sec.
Recipe 1a nano	40	20	10	4.5-5	130° 5 min.	170° 70 sec.
Recipe 4 nano	40	20	10	2	130° 5 min.	170° 70 sec.
Recipe 5 nano	40	20	10	11	130° 5 min.	170° 70 sec.
Recipe 6 nano	40	20	10	8	130° 4 min.	170° 70 sec.
Recipe 7 nano	40	20	10	2	100° 5 min.	170° 70 sec.

Application of crease resistant finish was performed using a laboratory type padding machine and foam applicator manufactured by Gaston Systems (Fig. 3.5).

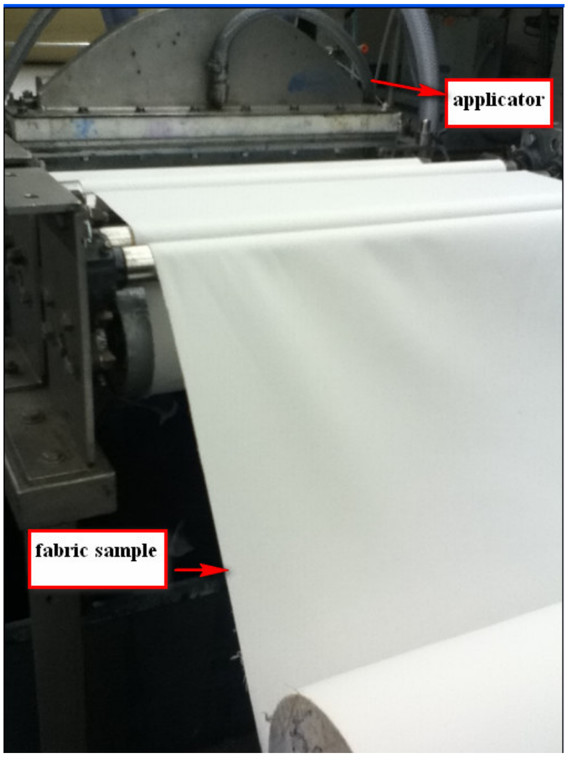


Figure 3.5 Laboratory type foam applicator

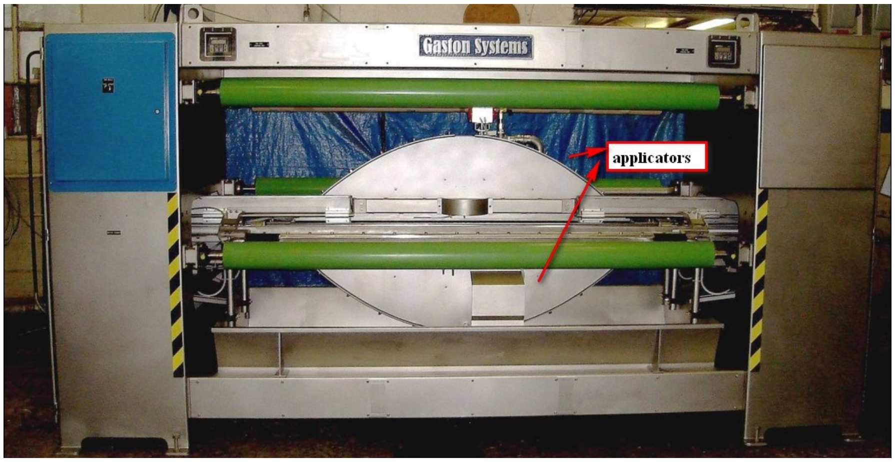


Figure 3.6 CFS parabolic applicator [51]

3.2. Methods

After finishing application the physical tests were done to the fabric samples which were treated with crease resistant finish. Test methods and instruments used in this experimental study are given in following section.

3.2.1. Tensile Strength

Tensile strength was measured by James H. Heal Titan Universal Strength Tester 2 as shown as Figure 3.7 at Textile Engineering Department, Gaziantep University.

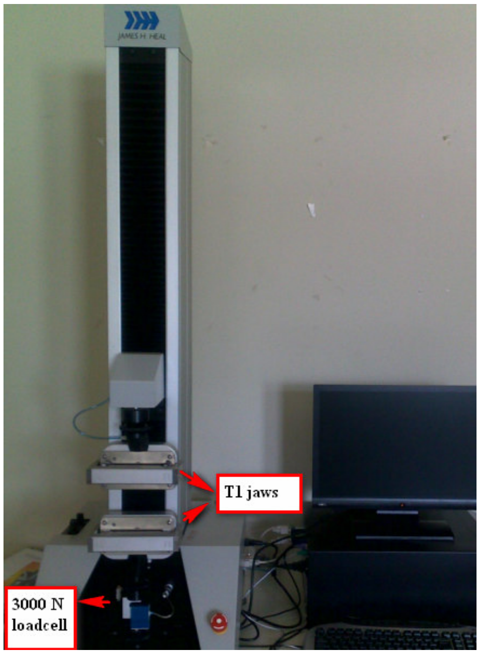


Figure 3.7 Titan universal strength tester 2 with 3000 N load cell

TS EN ISO 13934-1 ‘Tensile properties of fabrics-Part I: Determination of maximum force and elongation at maximum force using the strip method (200 mm-100 mm)’ was used to determine the tensile strength and elongation of fabric. 5 of warp direction, 5 of weft direction fabric samples (for each recipe) were tested. The tests output were obtained as tenacity (cN/tex) and extension (%) diagram and also mean values of tenacity, extension and CV%. Tenacity is defined the specific stress corresponding with the maximum force on a force/extension curve. Specific stress is a measurement of stress in the case of yarns as their cross-sectional area is not known (cN/tex). Elongation is the increase in length of the specimen from its starting length expressed in units of length. The fabric samples were tested at laboratory conditions with temperature 21±1° and relative humidity 65+2 % RH. 5 tests were done for each warp and weft direction of samples. Titan Universal Strength Tester was adjusted with T1 jaws and 3000 N load cell (Fig 3.7) for fabric samples. Tensile strength test results of warp and weft directions of fabric samples were given in Appendix A.

3.2.2. Tear Strength

Tear strength was also measured by James H. Heal Titan Universal Strength Tester 2. TS EN 13937-2 ‘Tear properties of fabrics- Part II: Determination of tear force of trouser–shaped test specimens’ was used to determine the tear strength (Fig 3.8). Similar to tensile strength tests, 5 trials warp and weft directions of fabric samples (for each recipe) were measured. The tests output were obtained as tear strength and CV%.

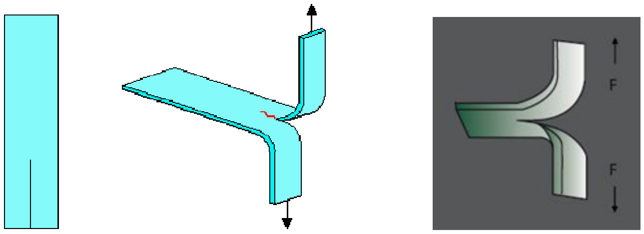


Figure 3.8 Trouser shaped test specimen

Tearing can occur when a local stress concentration or local damage results in the failure of one yarn, which increases the stress on remaining yarns. The fabric samples were tested at laboratory conditions with temperature 21±1° and relative humidity 65±2 % RH. Titan Universal Strength Tester was adjusted with T2 jaw and 600 N load cell (Fig 3.9). Tear strength results and CV% were given in Appendix B.

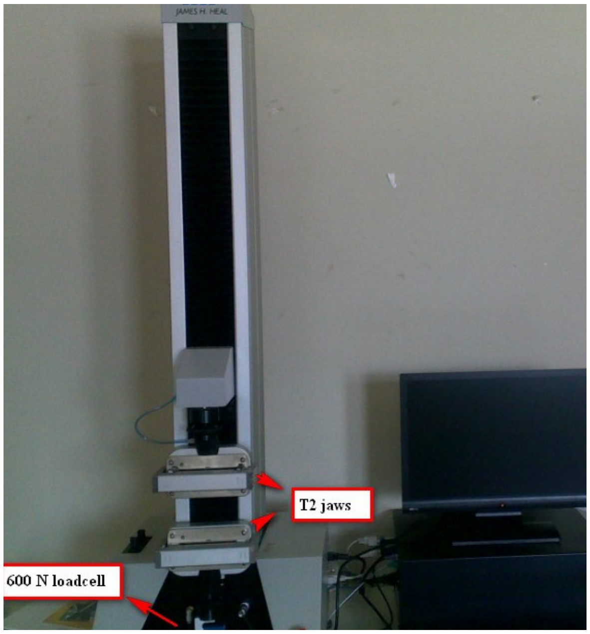


Figure 3.9 Titan universal strength tester 2 with 600N load cell

3.2.3. Crease Recovery Angle

Crease recovery angles were measured according to AATCC Test Method 66 ‘Wrinkle Recovery of Woven Fabrics: Recovery Angle-1998’ by James H. Heal & Co. Ltd. Crease Recovery Angle tester.

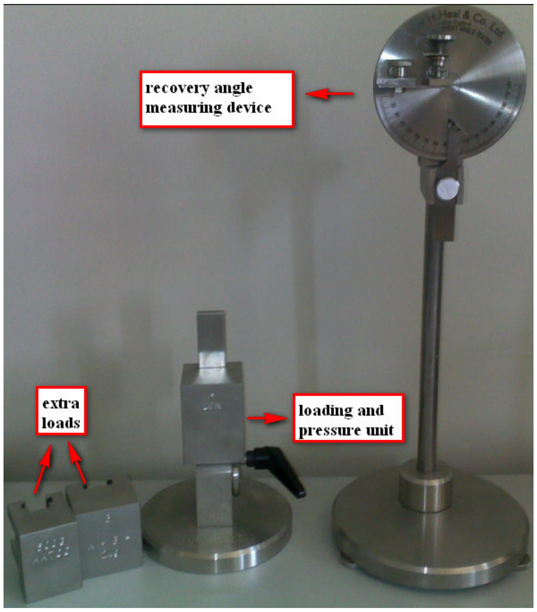


Figure 3.10 James H. Heal & Co. Ltd. crease recovery angle tester

The crease recovery angle tester is used to determine the recovery from creasing of a horizontally folded specimen by measuring the angle of recovery.

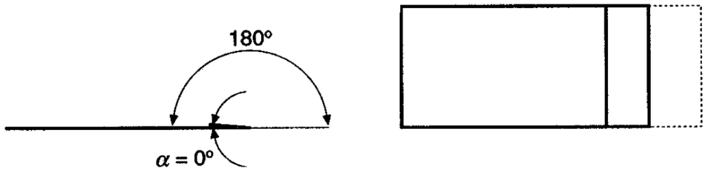


Figure 3.11 Before pressing load to fabric sample for crease recovery angle test

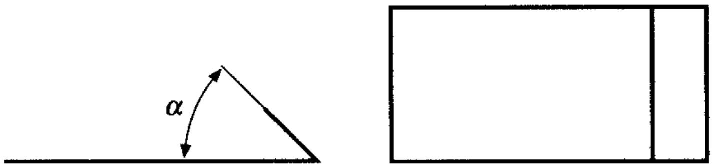


Figure 3.12 After pressing load to fabric sample for crease recovery angle test

Wrinkle recovery angle is the ability of a creased or wrinkled fabric to recover its original shape over time.

The fabric samples were prepared according to the standard and these were tested at laboratory conditions with temperature 21+1° and relative humidity 65±2 % RH. 12 specimens for each recipe were cut about 40x15 mm for each warp and weft direction of samples. The wrinkle recovery angles were recorded as the added total of warp and weft averages. The test results of warp and weft direction of fabric samples were given in Appendix C.

3.2.4. Abrasion Resistance

Abrasion resistance values were measured by Martindale Abrasion Tester. TS EN ISO 12947-3 'Determination of the abrasion resistance of fabrics by the Martindale method- Part 3: Determination of mass loss' standard was used.

Figure 3.13 Martindale abrasion tester

4 specimens were prepared for each fabric samples. The tests were done at laboratory conditions with temperature 21±1° and relative humidity 65±2 % RH. By means of this method; besides mass losses, fabric thickness differences after every cycle were also noted. The thickness was measured by Baker Fabric Thickness Gauge.

Figure 5.14 Fabric thickness gauge

Abrasion resistance is the ability of a surface to resist wearing due to contact with another surface moving with respect to it. Abrasion resistance and fabric thickness test results were given in Appendix D.

3.2.5. Spectrophotometric Measurement

Whiteness (WI) and yellowness (YI) indices were measured by Hunterlab Color Quest II. The device was adjusted D 65/10°. Fabric samples from each recipe were placed into sample clamp and the whiteness and yellowness indexes were obtained at laboratory conditions. The tests were done at laboratory conditions with temperature 21±1° and relative humidity 65±2 % RH.

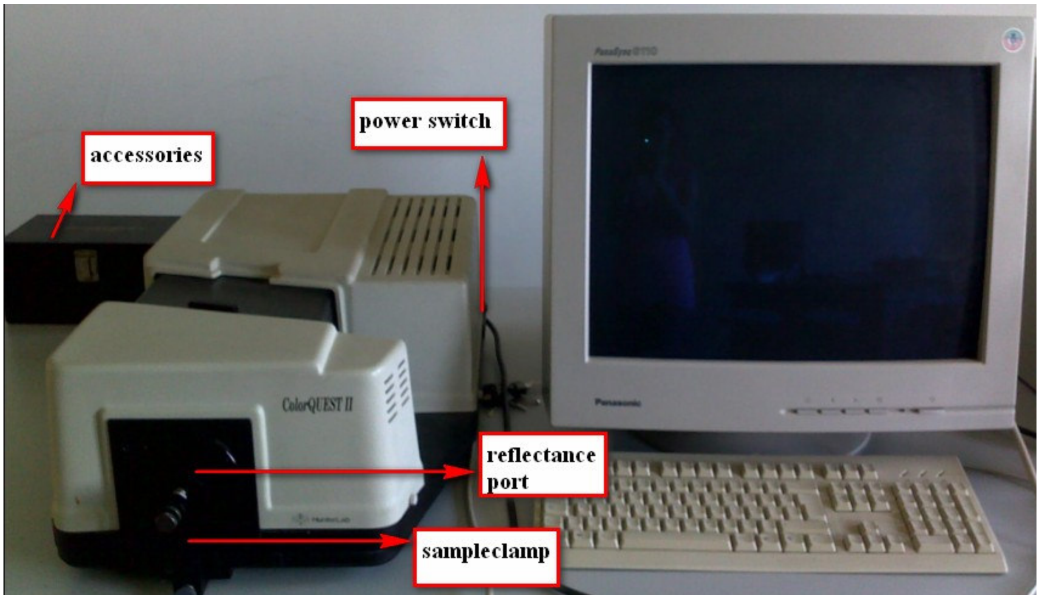


Figure 3.15 Hunterlab color quest II spectrophotometer

Whiteness indices (WI) are widely measured to yield numbers correlating closely with consumers' preferences for white colors.

Yellowness index (YI) measurements are used primarily to study degradation of white color from raw materials, processing, or subsequent service exposure. Whiteness indices and yellowness indices are given in Appendix E.

CHAPTER 4

RESULTS AND DISCUSSIONS

First group of samples are 100% woven cotton fabric from Kardesler Boya, Gaziantep, Turkey. These samples were tested to investigate the physical properties of 100% woven cotton fabric samples after crease resistant finish application by pad application with conventional and nano marked cross linking agent.

Second group of samples are 100% woven cotton fabric from Gaston Systems Laboratory, North Carolina, USA. These samples were also tested to investigate the physical properties of 100% woven cotton fabric samples after crease resistant finish application by pad and foam application with conventional and nano marked cross linking agent.

4.1. Evaluation of First Group of Samples

Conventional and nano marked cross linking agents (DMDHEU and Nanolink) were applied in different 7 recipes to the 100% woven cotton fabric from Kardesler Boya, Gaziantep, Turkey.

4.1.1. Tensile Strength –Extension – CV

Basic physical properties of a fabric sample are tensile strength and elongation values. These values affect the other physical properties like abrasion resistance.

In Appendix A, the mean tensile strength force, extension and CV% are listed. According to Table 4.1, the maximum tensile forces are 530.48N and 530.81N which belong to NK2 and K1 pH 11 warp directions. The minimum tensile forces are 76.57N and 104.45N which belong to K1 pH 2 and NK1 pH 2 warp directions. When the weft directions are considered the maximum tensile forces are 285.37N, 276.82N and 269.54N which belong to K2, NK2, NK1 pH 11.

It can be said that when pH is higher than 2 the tensile force is optimum, when pH=2 the lowest tensile force is emerged. And also nano marked crosslinking agent damaged the weft direction yarns less than conventional crosslinking agent.

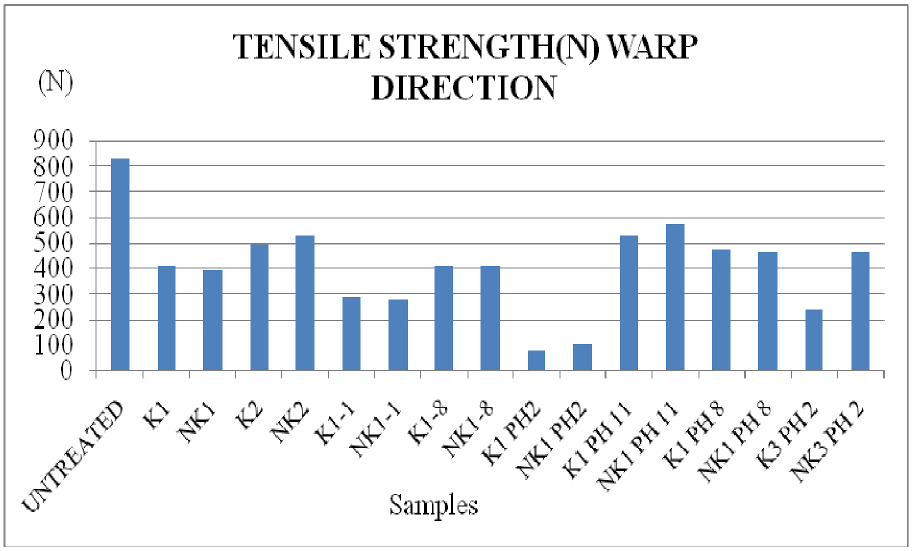


Figure 4.1 Mean tensile strength warp direction for first group of samples

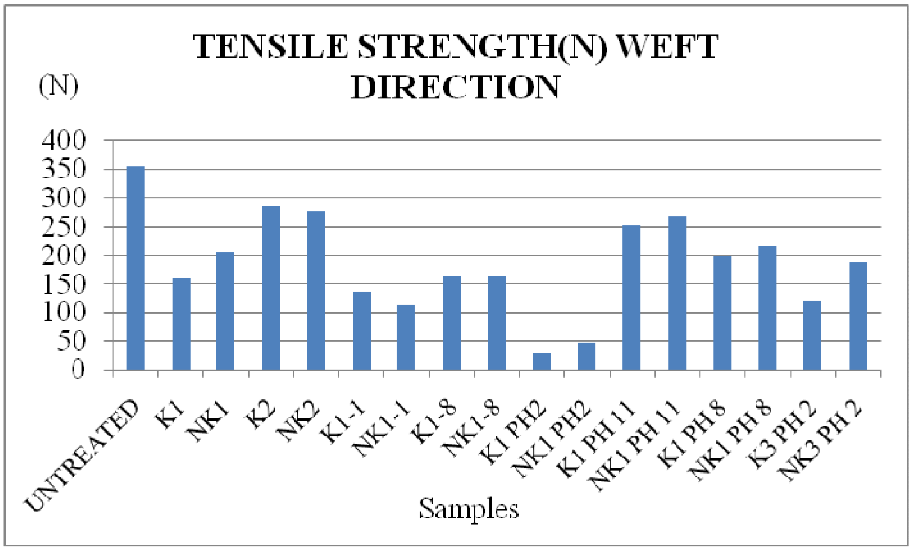


Figure 4.2 Mean tensile strength weft direction for first group of samples

Extension is illustrated in Figure 4.3 and 4.4 for different recipes. As shown in Table 4.1, the maximum extension values are 19.62% and 19.08% which belong to NK2 and K2 through warp direction and in Figure 6.2, 9.87% and 9.81% which belong to K2 and NK2 through weft direction.

The minimum extension values are 11.21% and 12.22% which belong to K1 pH2 and NK1 pH2 through warp direction and 3.86% and 4.55% which belong to K1 pH2 and NK1 pH2 through weft direction. Based to these results, it is clear that the maximum extension is obtained with pH4.5-5 value and the minimum extension is obtained with pH 2 value.

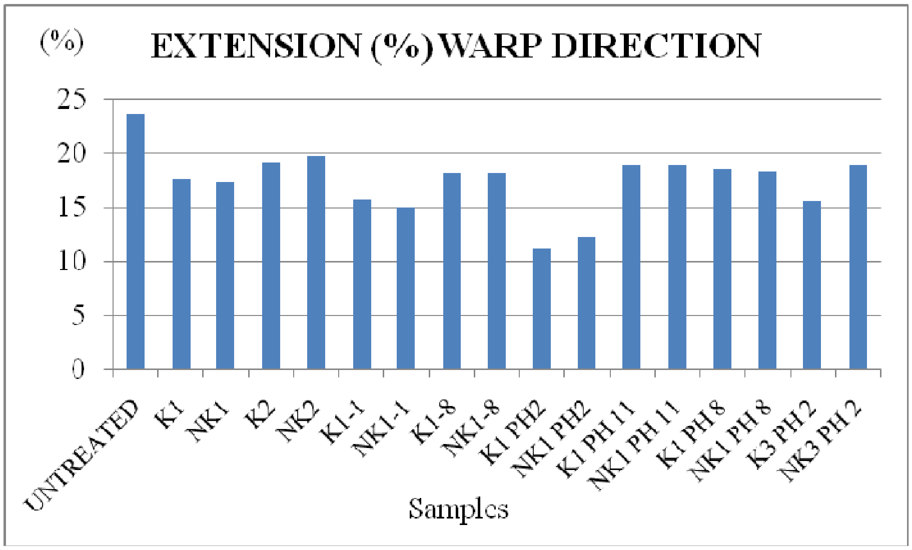


Figure 4.3 Mean extension warp direction for first group of samples

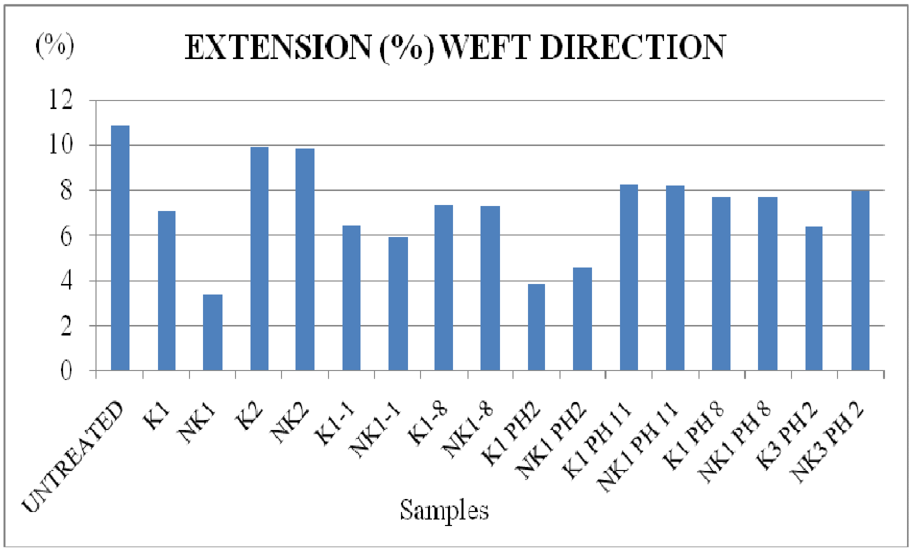


Figure 4.4 Mean extension weft direction for first group of samples

The coefficient of variation (CV) is a normalized measure of dispersion of a probability distribution. In the Table 4.1, it can be seen that the mean force and extension values with CV values. The minimum CV value is 1.89% which belongs to K1 pH8 through warp direction. Besides the minimum CV value is 3.03% which belong to NK1 pH8 through weft direction. It can be considered that conventional and nano marked crosslinking agent have similar effect on fabric sample. The maximum CV value is 19.05% which belongs to NK2 through warp direction and 24.14% which belongs to K1 pH2 through weft direction. It can be said that pH 8 value can cause minimum CV value.

Table 4.1 Mean tensile force, mean extension and CV values of first group of samples

SAMPLES	MEAN FORCE(N)	MEAN EXTENSION (%)	FORCE CV (%)	EXTENSION CV (%)
Untreated warp	834.57	23.51	3.47	1.81
Untreated weft	356.79	10.81	5.21	1.79
K1 warp	406.89	17.50	8.64	3.84
K1 weft	159.69	7.05	9.58	3.06
NK1 warp	393.91	17.31	3.36	1.54
NK1 weft	206.82	7.79	3.20	2.36
K2 warp	494.94	19.08	11.48	4.97
K2 weft	285.37	9.87	4.42	4.79
NK2 warp	530.48	19.62	19.05	8.31
NK2 weft	276.89	9.81	8.46	6.83
K1-1 warp	290.52	15.62	7.26	2.22
K1-1 weft	136.77	6.41	5.86	1.15
NK1-1 warp	278.60	15.01	7.11	2.30
NK1-1 weft	112.89	5.94	9.22	4.16
K1-8 warp	409.48	18.12	6.23	2.55
K1-8 weft	162.17	7.34	5.63	2.76
NK1-8 warp	407.21	18.10	2.81	1.98
NK1-8 weft	164.89	7.24	15.50	5.72
K1-pH2 warp	76.57	11.21	4.34	1.11
K1-pH2 weft	28.55	3.86	24.14	9.34
NK1 pH2 warp	104.45	12.22	6.73	3.12
NK1 pH2 weft	46.21	4.55	7.74	3.50
K1 pH11 warp	579.32	18.87	3.58	1.55
K1 pH11 weft	269.54	8.19	3.12	0.38
NK1 pH11 warp	579.32	18.87	3.58	1.55
NK1 pH11 weft	269.54	8.19	3.12	0.38
K1 pH8 warp	474.86	18.55	1.89	1.76
K1 pH8 weft	200.53	7.66	8.23	4.20
NK1 pH8 warp	465.52	18.20	7.43	3.62
NK1 pH8 weft	216.23	7.66	3.03	1.22
K3 pH2 warp	236.81	15.57	4.06	2.98
K3 pH2 weft	119.03	6.33	8.51	5.29
NK3 pH2 warp	463.55	18.84	11.92	4.00
NK3 pH2 weft	187.06	7.93	5.08	3.05

4.1.2. Tear Strength

Tear strength is an important physical property for textile materials. Tear strength gives information about the fabric can be caused during production and usage stage. Tear strength is a force that under definite conditions the resistance to start, to continue or to spread tearing situation. During tearing situation, yarns break one by one or by groups. Because of this reason, the strength of single yarn is important for whole fabric. Besides, fabric construction, finish application are also important and effective for tearing.

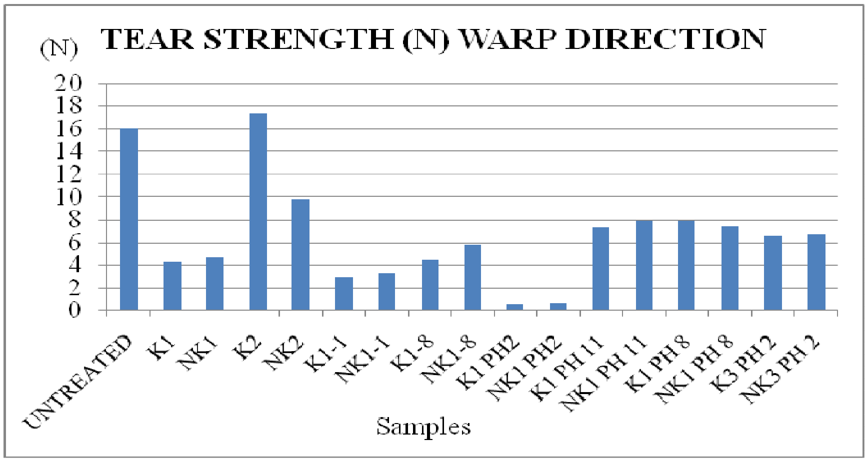


Figure 4.5 Mean tear strength force warp direction for first group of samples

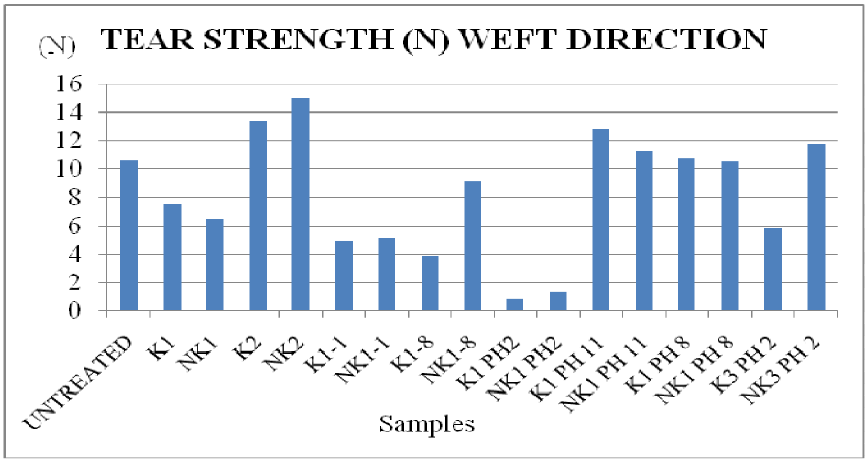


Figure 4.6 Mean tear strength force weft direction for first group of samples

In Table 4.2 it's clearly observed that the maximum tear force is 17.29N which belongs to K2 through warp direction and 14.97N which belongs to NK2 through weft direction. It can be considered that the resistance to tearing is much more in one step drying with both conventional and nano marked crosslinking agent.

Table 4.2 Mean tear force and mean CV % of first group of samples

SAMPLES	MEAN FORCE (N)	MEAN CV (%)
Untreated warp	16.02	3.36
Untreated weft	10.63	4.24
K1 warp	4.24	3.27
K1 weft	7.51	10.28
NK1 warp	4.64	14.53
NK1 weft	6.50	5.68
K2 warp	17.29	17.03
K2 weft	13.35	7.67
NK2 warp	9.80	36.39
NK2 weft	14.97	10.53
K1-1 warp	2.85	4.82
K1-1 weft	4.90	26.77
NK1-1 warp	3.22	40.39
NK1-1 weft	2.82	9.08
K1-8 warp	4.41	7.25
K1-8 weft	3.81	3.81
NK1-8 warp	5.74	6.42
NK1-8 weft	9.13	10.02
K1 pH2 warp	0.56	2.32
K1 pH2 weft	0.88	7.57
NK1 pH2 warp	0.66	7.50
NK1 pH2 weft	1.31	6.29
K1 pH11 warp	7.31	19.89
K1 pH11 weft	12.78	20.67
NK1 pH11 warp	7.88	20.13
NK1 pH11 weft	11.23	8.34
K1 pH8 warp	7.91	30.57
K1 pH8 weft	10.76	9.45
NK1 pH8 warp	7.41	9.01
NK1 pH8 weft	10.54	34.90
K3 pH2 warp	6.45	45.50
K3 pH2 weft	5.81	60.79
NK3 pH2 warp	6.63	29.38
NK3 pH2 weft	11.74	22.64

Coefficient of variation is also important in tearing process. The coefficient of variation can show the yarn distribution and quality in tearing process. The minimum CV value is 2.32% which belongs to K1 pH2 through warp direction, and the minimum CV value is 3.81% which belongs to K1-8 through weft direction according to Table 4.2. It can be said that lower pH value than pH 11 can obtain good results. The maximum CV value is 45.50% which belongs to K3 pH2 through warp direction and 60.79% which belongs to K3 pH2 weft direction. It’s clear that curing operation with stretching causes fabric demolition.

4.1.3. Crease Recovery Angle

Crease recovery angle is important for end use of textile materials. Especially for out wearing crease situation is a drawback, the bigger crease recovery angle, the better quality.

When the results are examined, the biggest angle is 289° which belongs to NK1-8. The second biggest angle is 287.25° which belongs to K1-8. It shows that two step drying, neutral pH, lowest catalyst ratio gives best result for crease recovery angle. The crosslinking type has not too much effect on crease recovery angle is the all conditions are same. But when the minimum angles are considered, they are 233° and 233.75° which belong to NK3 pH2 and NK1 pH11. When the drying conditions changed the crease recovery angle is affected negatively. And besides that when the pH values are low (pH=2) or high (pH=11), crease recovery angle decreases.

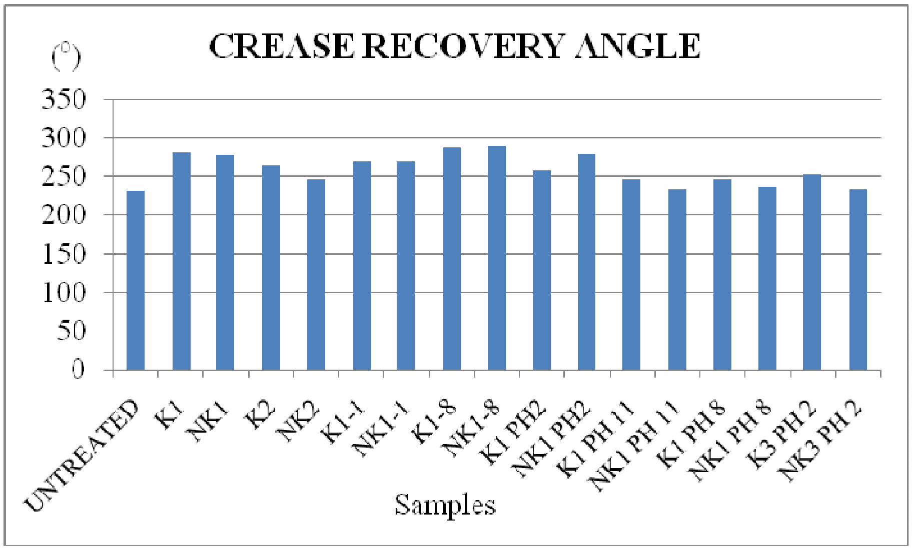


Figure 4.7 Crease recovery angle (warp+weft) for first group of samples

4.1.4. Abrasion Resistance

Abrasion resistance is one of the most important physical properties. The textile fabrics are against to forces during production and also end use step. The abrasion property is generally related with fabric properties but of course the fabric can be affected from finish applications. The main point is that the chemicals can destroy the fabric construction, so the yarns can be broken and lost their strength, so harmless chemicals should be selected.

In abrasion resistance tests done according to mass loss evaluations a preparation test is done to determine the test strokes. This preparation was done for a few samples and the test strokes of 2500, 5000, 7500 and 10000 were decided according to TSE Standards. When the abrasion tests are performed excessive damage in some samples at 7500 and 10000 cycles. So evaluations for mass loss (%) were done at 5000 cycle given in Table 4.3.

Table 4.3 Mass loss values (%) of second group of sample fabrics at 5000 cycles

Untreated	1.34%
K1	8.85%
NK1	2.86%
K2	25%
NK2	3.59%
K1-1	4.43%
NK1-1	100%
K1-8	5.86%
NK1-8	6.33%
K1 pH2	100%
NK1 pH2	100%
K1 pH11	2.53%
NK1 pH11	2.08%
K1 pH8	3.35%
NK1 pH8	4.54%
K3 pH2	4.54%
NK3 pH2	2.89%

Sample NK1-1, K1 pH2 and NK1 pH2 have the highest mass loss, after 5000 cycles the fabric samples are destroyed totally. Sample NK1 pH11 has the lowest mass loss, after abrasion test the fabric sample preserve 97.92% of itself.

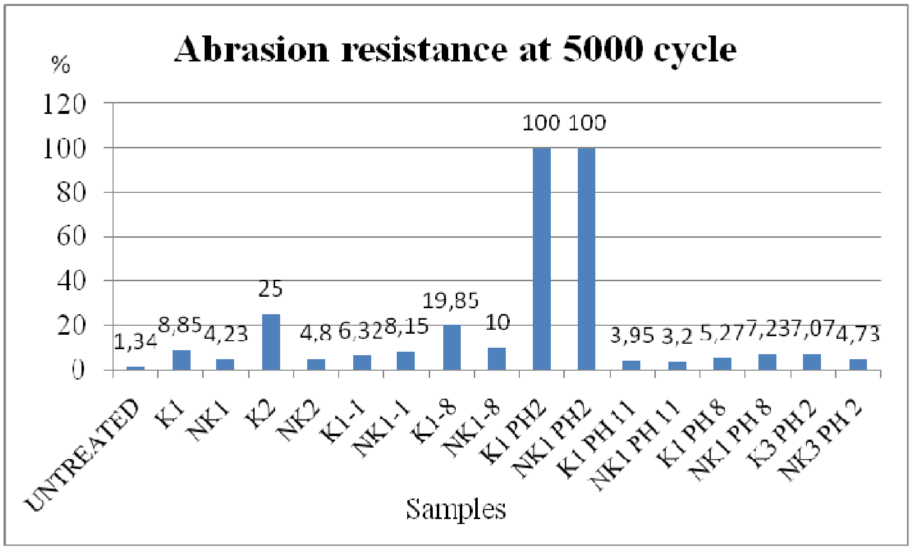


Figure 4.8 Mass loss (%) of sample fabrics after 5000 cycles for first group of samples

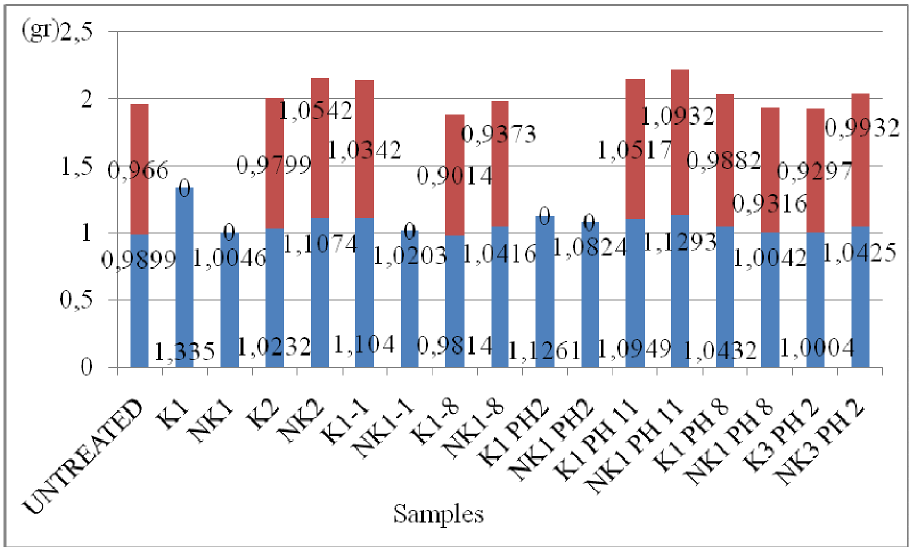


Figure 4.9 Mass values of for first group of samples before and after abrasion resistance test (blue column indicates before abrasion test, red column indicates after abrasion test)

When we look out the samples, lowest pH (pH=2) causes highest destroy. The best result is obtained with highest pH (pH=11). Based on this result, it is clear that lowest pH cause the abrasion resistance to lessen.

And also the mass losses for each sample are shown in Appendix D.

4.1.5. Spectrophotometric Measurement

Whiteness and yellowness indices are a part of quality fabric production. The color differences in samples cause customer dissatisfaction. The finish applications should not result color difference in other words yellowness. The spectrophotometers can be operated to measure the whiteness and yellowness indices and besides color difference between standard and sample fabric, brightness and etc. The yellowness and whiteness indices are compared and the yellowness and whiteness indices of K2, K1-8, NK1-8, NK1 pH11 and NK1 pH8 are close to the yellowness and whiteness indices of untreated fabric sample. The big differences of indices are with K1 pH2 and NK1 pH2 (Table 4.4)

The proximate result for whiteness indices is acquired with NK1-8, for yellowness indices is K1-8. But when we compare the samples both whiteness and yellowness indices NK1-8 has the optimum result. As a conclusion, when the ratio of crosslinking agent and catalyst is lowest, the whiteness and yellowness indices are affected in small quantities.

The indices and color differences are listed in Appendix E for each sample.

Table 4.4 Whiteness and yellowness indices for first group of samples

SAMPLES	WHITENESS INDICES	YELLOWNESS INDICES
Untreated	61.73	7.91
K1	55.84	9.70
NK1	54.02	10.02
K2	63.33	7.45
NK2	54.02	8.48
K1-1	54.99	9.40
NK1-1	50.43	11.07
K1-8	60.94	7.86
NK1-8	61.51	7.76
K1 pH2	-31.18	26.66
NK1 pH2	-19.84	28.04
K1 pH11	57.71	8.98
NK1 pH11	59.06	8.60
K1 pH8	67.22	5.84
NK1 pH8	61.33	7.13
K3 pH2	70.09	4.35
NK3 pH2	75.04	3.03

4.2. Evaluation of Second Group of Samples

4.2.1. Tensile Strength –Extension – CV

Basic physical properties of a fabric sample are tensile strength and elongation values. These values affect the other physical properties like abrasion resistance.

In Appendix A, the mean tensile strength force, extension and CV% are listed. According to Figure 4.10, the maximum tensile force is 1584.95N which belongs to recipe 5 nano foam through warp direction. The minimum tensile force is 238.31N which belongs to recipe 4 pad through warp direction. When the weft direction is considered the maximum tensile force is 892.57N which belongs to recipe 5 nano pad. The minimum tensile force is 92.79N through weft direction.

It can be definable that foam application with nano marked crosslinking agent causes high tensile strength through warp direction, but for weft direction pad application with nano marked crosslinking agent effects positively. It can be said that nano marked crosslinking agent can be used instead of conventional crosslinking agent.

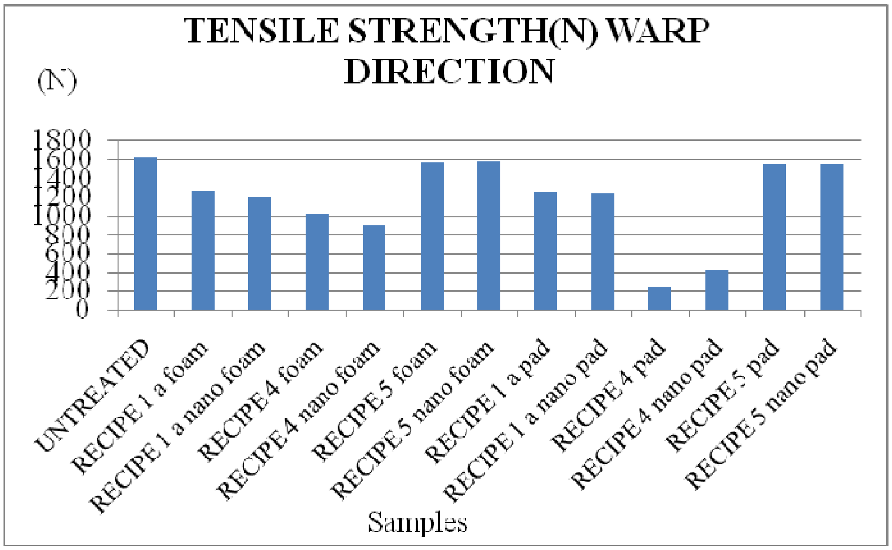


Figure 4.10 Mean tensile strength warp direction for second group of samples

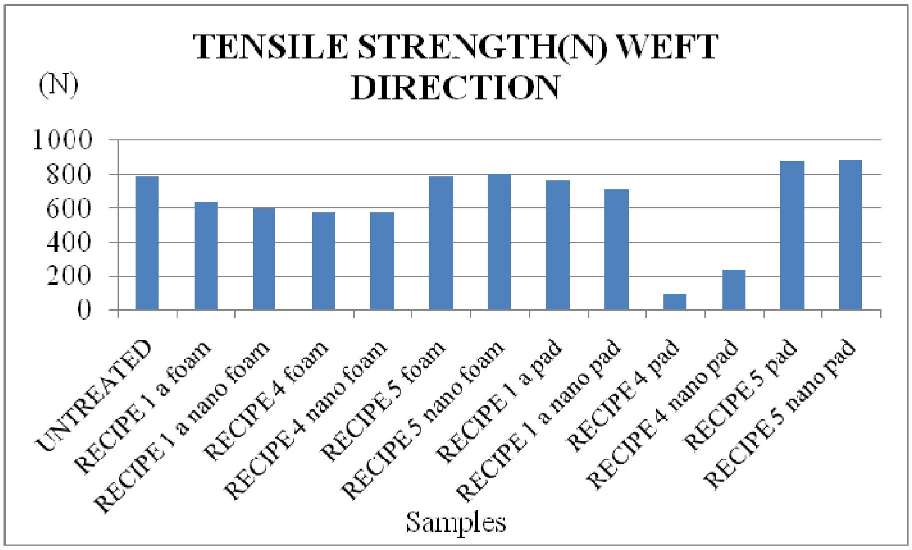


Figure 4.11 Mean tensile strength weft direction for second group of samples

Extension is illustrated in Table 4.5 for different recipes. As shown in Table 4.5, the maximum extension value is 21.67% which belongs to Recipe 5 pad through warp direction and 12.37% which belongs to Recipe 5 nano pad through weft direction.

The minimum extension values are 9.91% which belongs to Recipe 4 pad through warp direction and 5.19% which belongs to Recipe 4 pad through weft direction.

Based to these results, it is clear that the maximum extension is obtained with pad application with both conventional and nano marked crosslinking agents and the minimum extension is also obtained with pad application with conventional crosslinking agent. Foam application doesn't have any effect on extension.

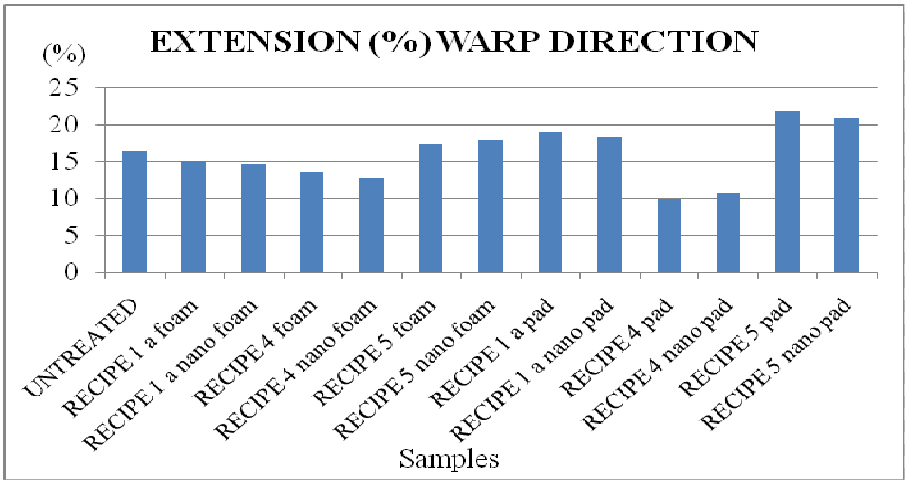


Figure 4.12 Mean extension warp direction for second group of samples

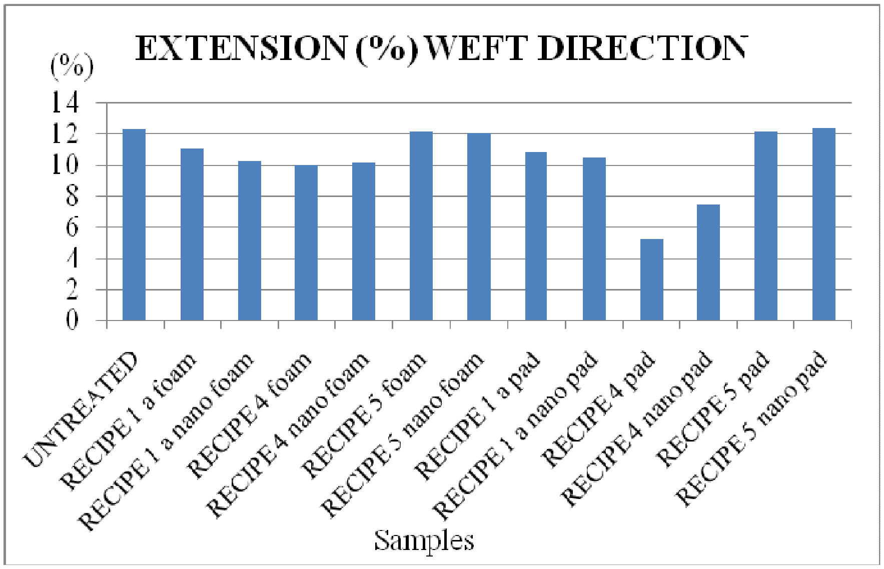


Figure 4.13 Mean extension weft direction for second group of samples

The coefficient of variation (CV) is a normalized measure of dispersion of a probability distribution. CV value should be low to get a quality fabric. The minimum CV value is 1.33% which belongs to Recipe 5 foam through warp direction. Besides the maximum CV value is 6.67% which belongs to Recipe 4 foam through warp direction. It can be considered that foam application with different pH values have different effects on fabric sample. Low pH (pH=2) value causes to increase CV value but high pH value (pH=11) causes to decrease CV value through warp direction. The minimum CV value is 1.98% which belongs to Recipe 1a nano pad through and the maximum CV value is 16.13% which belongs to Recipe 4 pad through weft direction. It can be said that pad application effects weft direction of fabric samples for CV values. Neutral pH (pH=4.5-5) causes best result through weft direction.

Table 4.5 Mean tensile force, mean extension and CV values of second group of samples

SAMPLES	MEAN FORCE(N)	MEAN EXTENSION (%)	FORCE CV (%)	EXTENSION CV (%)
Untreated warp	1631.26	16.49	3.82	2.52
Untreated weft	791.97	12.24	2.65	1.25
Recipe 1a foam warp	1274.44	15.00	4.82	2.98
Recipe 1a foam weft	634.67	11.00	4.21	1.68
Recipe 1a nano foam warp	1210.54	14.59	6.38	3.76
Recipe 1a nano foam weft	601.63	10.27	6.22	2.59
Recipe 4 foam warp	1028.05	13.53	6.67	3.29
Recipe 4 foam weft	576.38	10.00	8.23	5.59
Recipe 4 nano foam warp	902.06	12.71	6.51	6.95
Recipe 4 nano foam weft	582.03	10.14	5.89	3.46
Recipe 5 foam warp	1563.89	17.33	1.33	3.69
Recipe 5 foam weft	790.60	12.11	2.16	1.73
Recipe 5 nano foam warp	1584.95	17.92	1.55	3.60
Recipe 5 nano foam weft	806.75	11.96	4.21	2.44
Recipe 1a pad warp	1263.82	18.93	4.21	2.08
Recipe 1a pad weft	763.89	10.80	3.85	2.89
Recipe 1a nano pad warp	1253.46	18.25	3.50	3.58
Recipe 1a nano pad weft	716.71	10.45	1.98	1.99
Recipe 4 pad warp	238.31	9.91	5.86	4.26
Recipe 4 pad weft	92.80	5.19	16.13	5.07
Recipe 4 nano pad warp	423.46	10.71	3.21	2.34
Recipe 4 nano pad weft	233.81	7.45	10.55	2.40
Recipe 5 pad warp	1549.74	21.67	4.63	3.30
Recipe 5 pad weft	879.42	12.09	2.69	2.20
Recipe 5 nano pad warp	1554.44	20.79	3.03	1.70
Recipe 5 nano pad weft	892.57	12.37	3.42	2.40

4.2.2. Tear Strength

In Table 4.6, the maximum tear force is 21.72N which belongs to Recipe 1a foam through warp direction and 23.09N which belongs to Recipe 5 nano foam through weft direction. It can be considered that the resistance to tearing is much more when foam application is applied with neutral pH value through warp direction. And also for weft direction, foam application is a determiner point for tear resistance. The foam application with high pH value (pH=11) cause maximum tear force through weft direction.

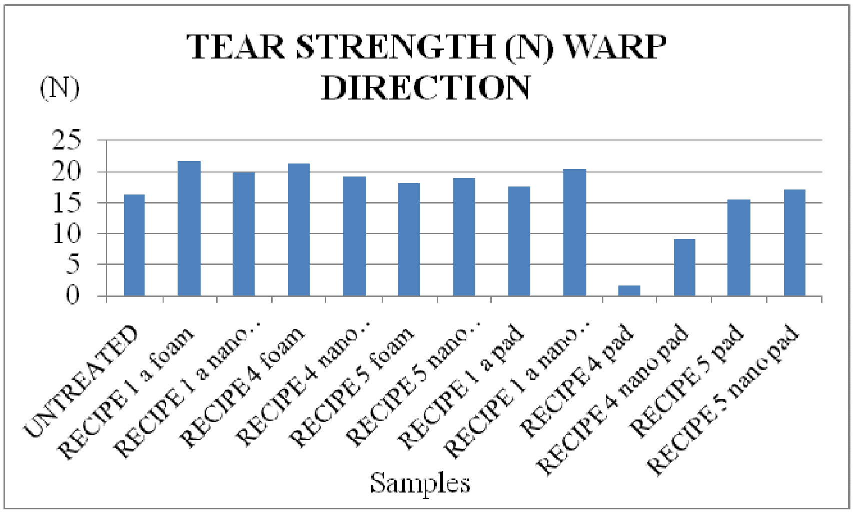


Figure 4.14 Mean tear strength force warp direction for second group of samples

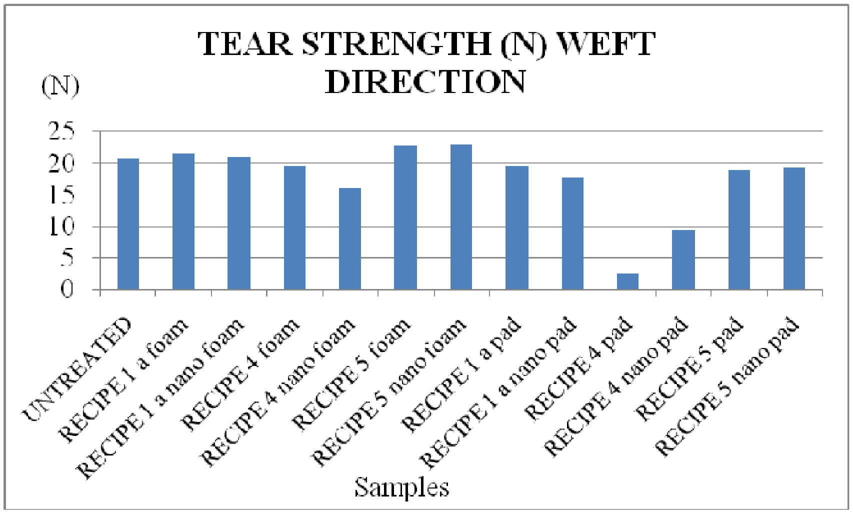


Figure 4.15 Mean tear strength force weft direction for second group of samples

Coefficient of variation is also important in tearing process. The coefficient of variation can show the yarn distribution and quality in tearing process. The minimum CV value is 0.88% which belongs to Recipe 1a nano foam through warp direction, and the minimum CV value is 0.87% which belongs to Recipe 5 foam through weft direction according to Table 4.6. It can be said that foam application destroys fabric samples minimum degree. The maximum CV value is 13.98% which belongs to Recipe 4 pad through warp direction and 26.69% which belongs to Recipe 4 nano pad according to Table 4.6. It's clear that pad application with low pH (pH=2) destroys yarn distribution and causes high CV values.

Table 4.6 Mean tear force and mean CV % of second group of samples

SAMPLES	MEAN FORCE (N)	MEAN CV (%)
Untreated warp	16.50	4.33
Untreated weft	20.71	0.66
Recipe 1a foam warp	21.72	4.84
Recipe 1a foam weft	21.55	1.41
Recipe 1a nano foam warp	19.93	0.88
Recipe 1a nano foam weft	21.11	2.39
Recipe 4 foam warp	21.30	2.62
Recipe 4 foam weft	19.71	3.04
Recipe 4 nano foam warp	19.32	2.73
Recipe 4 nano foam weft	16.01	4.19
Recipe 5 foam warp	18.10	3.96
Recipe 5 foam weft	22.77	0.87
Recipe 5 nano foam warp	19.06	1.13
Recipe 5 nano foam weft	23.09	1.40
Recipe 1a pad warp	17.52	1.96
Recipe 1a pad weft	19.50	6.26
Recipe 1a nano pad warp	20.45	3.14
Recipe 1a nano pad weft	17.72	4.99
Recipe 4 pad warp	1.59	13.98
Recipe 4 pad weft	2.54	11.09
Recipe 4 nano pad warp	9.02	7.41
Recipe 4 nano pad weft	9.21	26.69
Recipe 5 pad warp	15.63	3.97
Recipe 5 pad weft	18.87	5.16
Recipe 5 nano pad warp	17.21	3.91
Recipe 5 nano pad weft	19.25	2.65

4.2.3. Crease Recovery Angle

When the results are examined, the biggest angle is 240.5° which belongs to Recipe 4 nano pad. It shows that pad application with nano marked crosslinking agent and low pH value causes biggest crease recovery angle. But when the minimum angle is considered, it is 163° which belongs to Recipe 5 foam. It illustrates that low pH (pH=2) value results best crease recovery angle, the high pH (pH=11) value results worst crease recovery angle. When all results are examined foam application causes lower crease recovery angle than pad application.

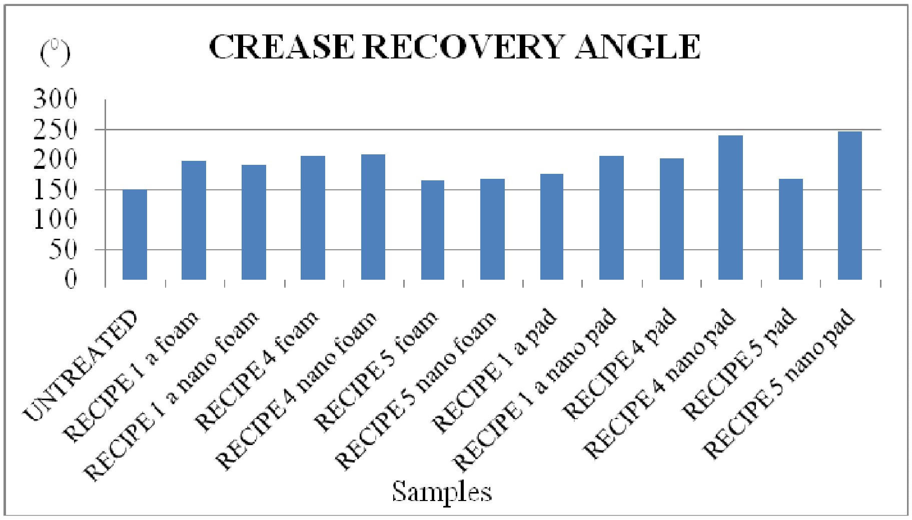


Figure 4.16 Crease recovery angle (warp+weft) for second group of samples

4.2.4. Abrasion Resistance

In abrasion resistance tests done according to mass loss evaluations a preparation test is done to determine the test strokes. This preparation was done for a few samples and the test strokes of 2500, 5000, 7500 and 10000 were decided according to TSE Standards. Evaluations for mass loss (%) were done at 10000 cycles given in Table 4.7.

Table 4.7 Mass loss values (%) of second group of sample fabrics at 10000 cycles

Untreated	1.53%
Recipe 1 a foam	0.86%
Recipe 1 a nano foam	0.80%
Recipe 4 foam	0.40%
Recipe 4 nano foam	1.44%
Recipe 5 foam	0.27%
Recipe 5 nano foam	1.17%
Recipe 1 a pad	1.93%
Recipe 1 a nano pad	1.10%
Recipe 4 pad	100%
Recipe 4 nano pad	1.44%
Recipe 5 pad	0.27%
Recipe 5 nano pad	1.17%

Figure 4.17 illustrates the mass loss values of all samples at 10000 cycles. Recipe 4 pad has the highest mass loss, after 2500 cycles the fabric samples are destroyed totally. Recipe 5 foam and Recipe 5 pad have the lowest mass loss, after abrasion test the fabric samples lost only 0.27% of their selves.

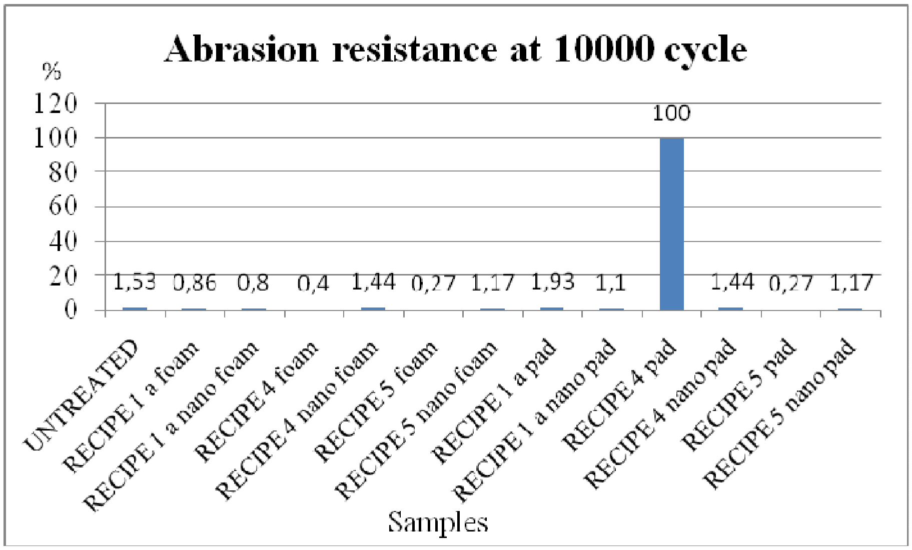


Figure 4.17 Mass loss (%) for second group of sample fabrics after 10000 cycles

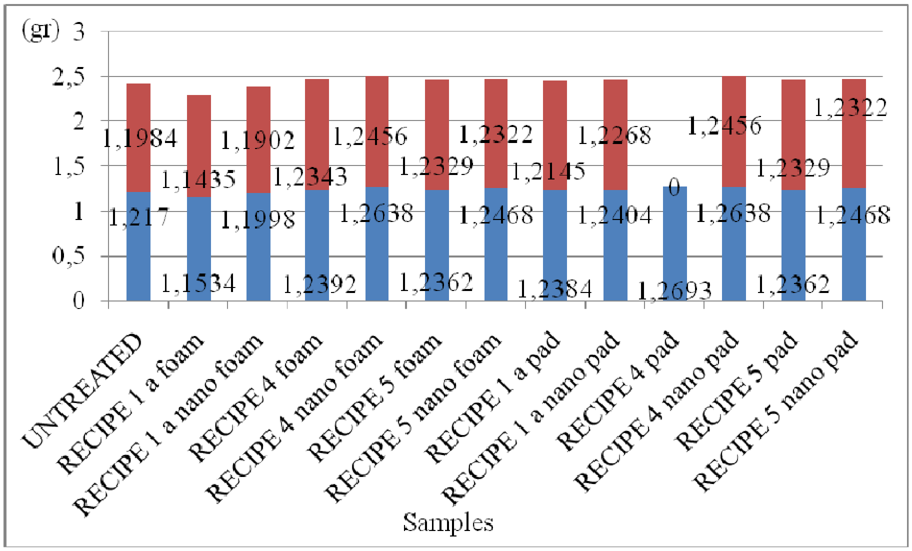


Figure 4.18 Mass values for second group of samples before and after abrasion resistance test (blue column indicates before abrasion test, red column indicates after abrasion test)

When we look out the samples, pad application with lowest pH (pH=2) causes highest destroy. The best result is obtained with foam application with lowest pH (pH=2). Based on this result, it is clear that foam application has smaller damage than pad application.

And also the mass losses for each sample are shown in Appendix D.

4.2.5. Spectrophotometric Measurement

The yellowness and whiteness indices are compared and the yellowness and whiteness indices of Recipe 1a foam, Recipe 1a nano foam, Recipe 4 foam and Recipe 4 nano foam are close to the yellowness and whiteness indices of untreated fabric sample. The big differences of indices are with Recipe 4 pad, Recipe 5 nano foam and Recipe 5 nano pad as shown in Table 4.8.

The best result belongs to Recipe 1a nano foam. It shows that when the pH value is neutral the color difference is reasonable. But when we increase or decrease the pH value the color illustrates differences. And also crosslinking agent effects very small when the samples treated with conventional and nano marked crosslinking agent compared.

Generally samples treated with foam application shows best results for whiteness and yellowness indices.

The indices and color differences are listed in Appendix E for each sample.

Table 4.8 Whiteness and yellowness indices for second group of samples

SAMPLES	WHITENESS INDICES	YELLOWNESS INDICES
Untreated	73.08	2.97
Recipe 1 a foam	74.06	2.41
Recipe 1 a nano foam	72.66	2.90
Recipe 4 foam	72.21	3.15
Recipe 4 nano foam	74.11	2.08
Recipe 5 foam	71.70	3.23
Recipe 5 nano foam	31.92	15.21
Recipe 1 a pad	71.18	3.62
Recipe 1 a nano pad	72.52	3.09
Recipe 4 pad	25.31	16.51
Recipe 4 nano pad	67.02	4.92
Recipe 5 pad	70.06	3.75
Recipe 5 nano pad	48.56	10.64

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Nanotechnology takes part in textile industry. Especially for finishing treatments, nano marked chemicals are produced and applied. There are many alternatives for crosslinking agents, nano marked crosslinking agents become also important in finishing applications.

Foam application has been valid since 1970s, but nowadays Chemical Foam System (CFS) method takes part much more than past times. There are lots of benefits with CFS application technique.

There are two different application techniques in this thesis, and also there are two different crosslinking agents with different particle size.

First group of samples were treated and the physical tests were done at Gaziantep University Laboratory, Gaziantep, Turkey. Tensile strength, tear strength, crease recovery angle, abrasion resistance and whiteness/yellowness indices measurement were completed and the differences between two different crosslinking agents with different particle size were evaluated.

In second part, samples were treated with crease resistant finish by two different methods (padding and foaming application) in Gaston Systems Laboratory, North Carolina, USA. After finish application, similar to first group of samples, physical tests were performed and the resulting differences between padding and foaming application were compared.

The conclusions are given as follows;

The First Group of Samples

Padding application with conventional crosslinking agent (DMDHEU) and nano marked crosslinking agent (Nanolink)

- *Tensile Strength*

The values of first group of samples have significant differences. The DMDHEU and nano marked crosslinking treatment decreased tensile strength of the fabrics between

36%-90%. But the difference between both crosslinking agents can not be cared so much; the results of DMDHEU and Nanolink are similar to each other.

- *Tear Strength*

The results are similar when we compared the DMDHEU and Nanolink. But when conditions are changed, especially at low pH values tear strength decreased about 95%.

- *Crease Recovery Angle*

Crease recovery angles are between 233.75°-289.00°. pH value is one of the effective parameter for crease recovery angle, for example high pH values (pH=11) cause low angle values. Low pH values cause better angles than high pH value. The best results are obtained with neutral pH values (pH=4.5-5). When the crosslinking type is considered the angle differences are not significantly discrete. The difference is about 5-20°.

- *Abrasion Resistance*

Pad application with two different particle size crosslinking agents damaged fabric samples too much, based on the reason some of the fabric samples are rubbed off totally. So the comparison is done after 5000 cycles.

After 5000 cycles, NK1-1, NK1 pH2 and K1 pH2 are totally rubbed off. It shows that low pH values (pH= 2) are harmful for fabric samples and also fabric samples are damaged by when pH value is neutral (pH=4.5-5) with nanolink crosslinking agent and 1:1 catalyst ratio. The results show that high pH value with both crosslinking agents causes less mass loss.

- *Whiteness/ Yellowness Indices*

The best results are obtained at pH 4.5-5 with both crosslinking agent. According to results low pH increase yellowness, decrease whiteness indices. The Nanolink and DMDHEU did not cause big differences. But pH value causes big differences, at pH=2, the difference between untreated sample is 150%.

The Second Group of Samples

Chemical Foam System (CFS) application and pad application with conventional (DMDHEU) and nano marked (Nanolink) crosslinking agent.

- *Tensile Strength*

Tensile strength values of second group of samples have less difference except Recipe 4 pad. The low pH value (pH=2) and pad application cause damage in fabric sample structure. The tensile strength decrease is about 85% according between untreated fabric sample and Recipe 4 pad treated fabric sample. The best result is obtained with Recipe 5 nano foam application, the decrease is about only 3%. There is not any substantial difference between pad application and foam application treatments.

- *Tear Strength*

When the results are compared in general the values are similar to each other. But such as tensile strength results, Recipe 4 pad has the lowest force value, also Recipe 4 nano pad has the highest CV degrees.

Based on these consequences Recipe 4 pad application with DMDHEU and Nanolink causes damage the fabric samples. The applied force decrease is about 90% for Recipe 4 pad.

- *Crease Recovery Angle*

Crease recovery angles are in order between 163°-240.5°. The biggest angle is obtained with Recipe 4 nano pad, but when the other paramaters of this recipe are examined, the only advantage of this recipe is having biggest angle. If the comparison is made according to pH values, angle result with low pH is bigger than angle result obtained with high pH value.

- *Abrasion Resistance*

Recipe 4 pad is a big problem for abrasion resistance test. The fabric samples treated with Recipe 4 pad are damaged totally at 2500 cycles.

After 10000 cycles, Recipe 5 foam and Recipe 5 pad still have their mass of 99.73%. The result shows that high pH makes fabric samples strong.

- *Whiteness/Yellowness Indices*

The best result is obtained with Recipe 1a nano foam. After treatment this recipe shows best similarity with untreated fabric sample. When pH value is 4.5-5 the color change of fabric sample is minimum. But at pH=2 fabric turns to yellowish even brownish. The whiteness indices difference with untreated sample is about 65%. When pH 11 is evaluated, pH 11 with DMDHEU has similar results with untreated sample, but pH 11 with Nanolink cause color change on fabric sample.

- *Over-all evaluation*

The over-all evaluation to define the most appropriate crease-recovery treatment recipe for cotton fabric has been done via multi-axial graphs. Those graphs included the axes belonging to mechanical properties measured and all data obtained by measurements plotted on the axes; then the area formed after combining the plots were calculated in unit. The evaluation has been done according to the following assumption: "The higher the tensile strength (in warp and weft directions), the tear strength (in warp and weft directions), the crease recovery angle (in warp and weft directions), the whiteness index and the abrasion resistance retention (as the ratio of abraded mass to total fabric mass), the greater the area and the more acceptable the recipe is". The multi-axial graphs of the recipes are given in Appendix F and the tables below are showing the area calculated. The results showed that for both cotton samples used in the study (either first of second group) and for both treatments (either pad or foam application), the most optimum crease recovery treatment formula has been obtained as following (remarked as NK1 pH11 / recipe 5)

- Crease recovery agent with smaller particle size (nano-labeled) with 1:4 catalyst ratio
- Softener with 1:2 agent ratio
- Curing at 130° for 5 minutes and condensation at 170° for 1 minute
- Application pH : 11

Besides these results, we found that our conclusion could be applied both cotton fabric samples used in the study since the results belonging to each group were comparable. For the samples 1 and 2, the same recipe gave the best optimum results and they showed similar responses in terms of tensile, tear strength and abrasion after treating with crease recovery agents. Another output of the study has been the consistency with the cotton fiber nature; where it gives moderate resistance at alkali environment as we derived the best optimum recipe pH as 11.

Table 5.1 Matlab area calculation of the first group of samples

RECIPES	TOTAL AREAS
Untreated	106041.29
K1	31156.94
NK1	36037.10
K2	56810.00
NK2	56592.00
K1-1	21859.00
NK1-1	18697.00

K1-8	31895.96
NK1-8	32567.78
K1pH2	5983.03
NK1 pH2	7717.30
K1 pH11	52253.75
NK1 pH11	**58915.58**
K1 pH8	39896.24
NK1 pH8	40856.86
K3 pH2	18074.41
NK3 pH2	36714.49

Table 5.2 Matlab area calculation of the second group of samples

RECIPES	TOTAL AREAS
Untreated	428748.41
Recipe 1a foam	274072.98
Recipe 1a nano foam	246957.31
Recipe 4 foam	203675.11
Recipe 4 nano foam	118372.92
Recipe 5 foam	411641.41
Recipe 5 nano foam	**424597.66**
Recipe 1a pad	323732.51
Recipe 1a nano pad	303638.60
Recipe 4 pad	11509.14
Recipe 4 nano pad	40941.31
Recipe 5 pad	452494.67
Recipe 5 nano pad	**460204.77**

APPENDIX A
TENSILE STRENGTH OF FIRST GROUP AND SECOND GROUP OF SAMPLES

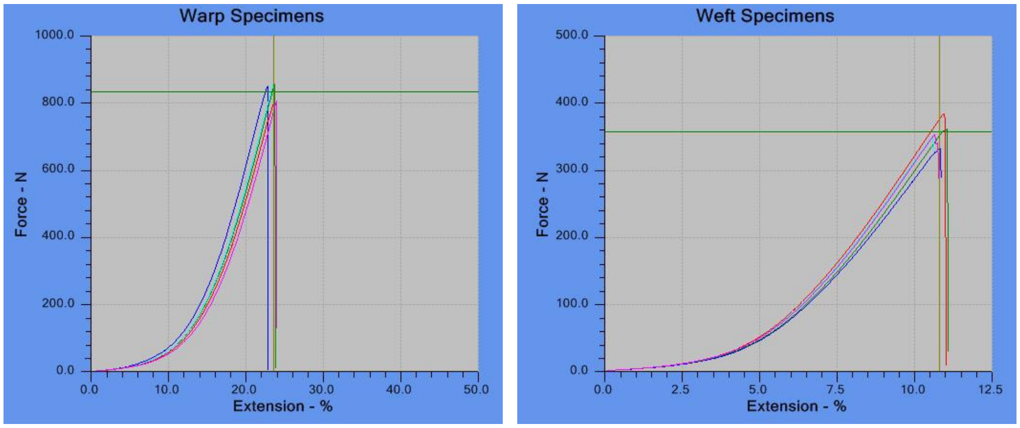


Figure A.1 Tensile strength-extension chart of untreated sample warp and weft directions in first group of samples

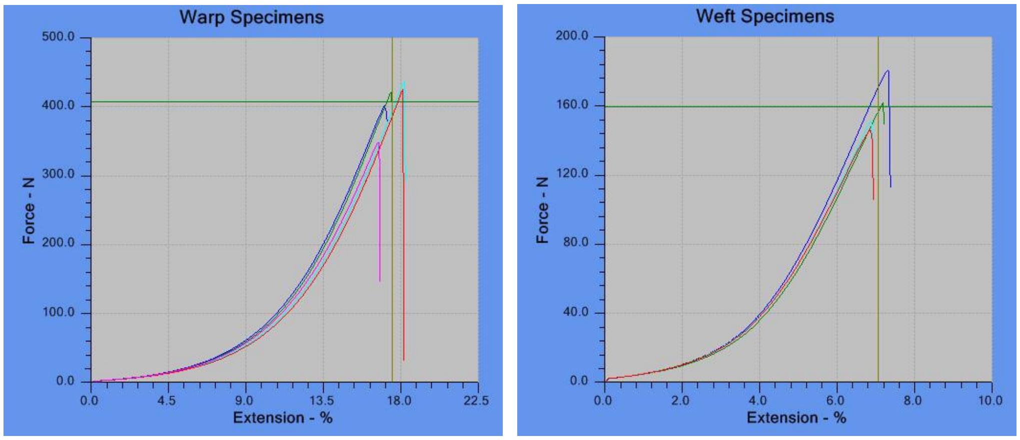


Figure A.2 Tensile strength-extension chart of K1 warp and weft directions in first group of samples

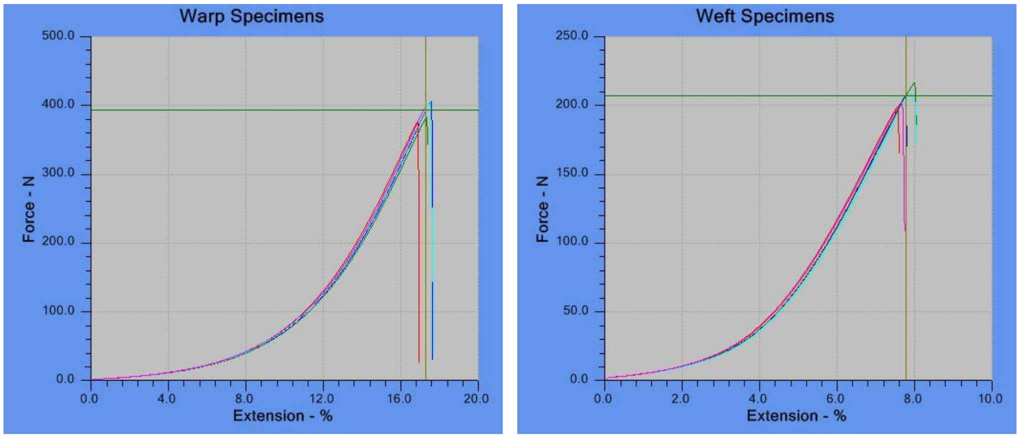


Figure A.3 Tensile strength-extension chart of NK1 warp and weft directions in first group of samples

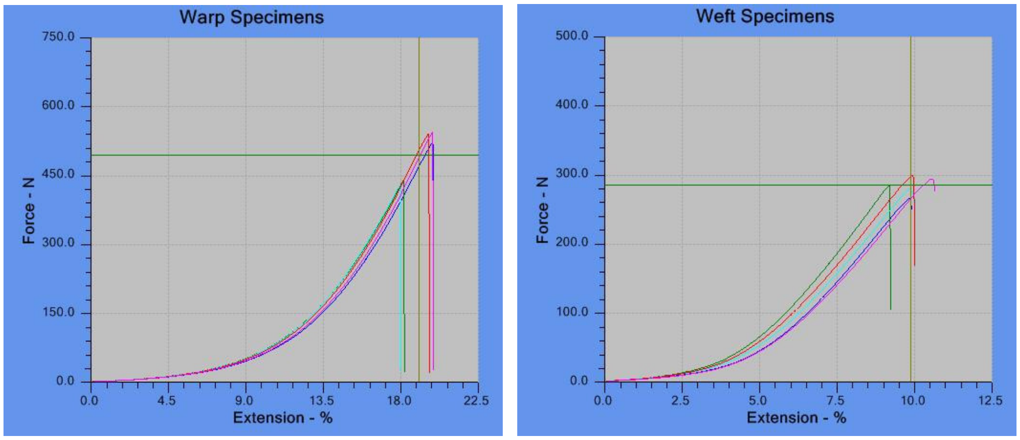


Figure A.4 Tensile strength-extension chart of K2 warp and weft directions in first group of samples

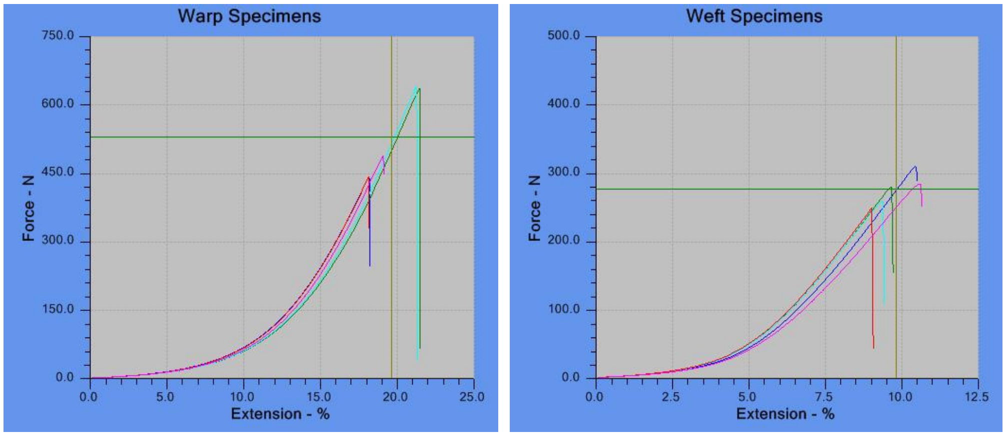


Figure A.5 Tensile strength-extension chart of NK2 warp and weft directions in first group of samples

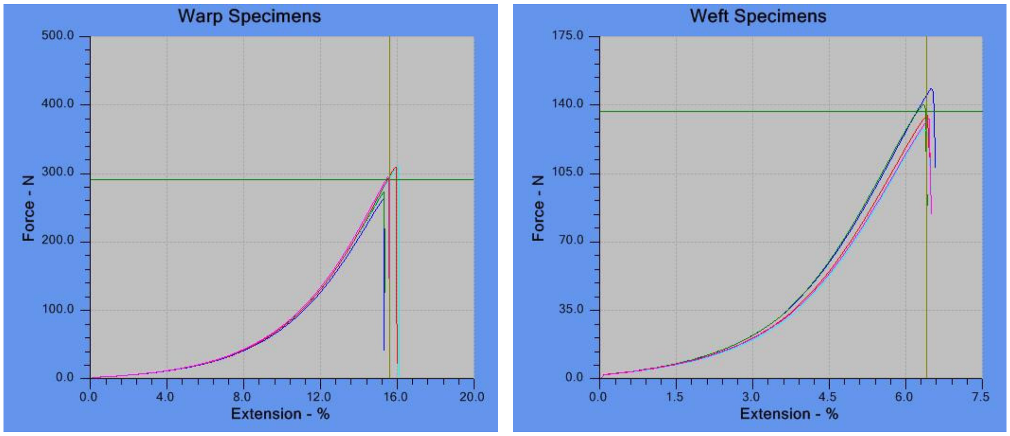


Figure A.6 Tensile strength-extension chart of K1-1 warp and weft directions in first group of samples

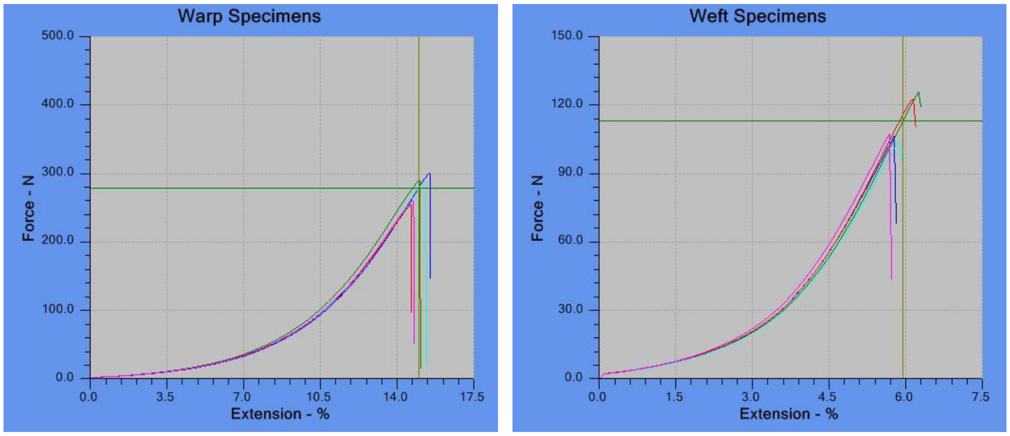


Figure A.7 Tensile strength-extension chart of NK1-1 warp and weft directions in first group of samples

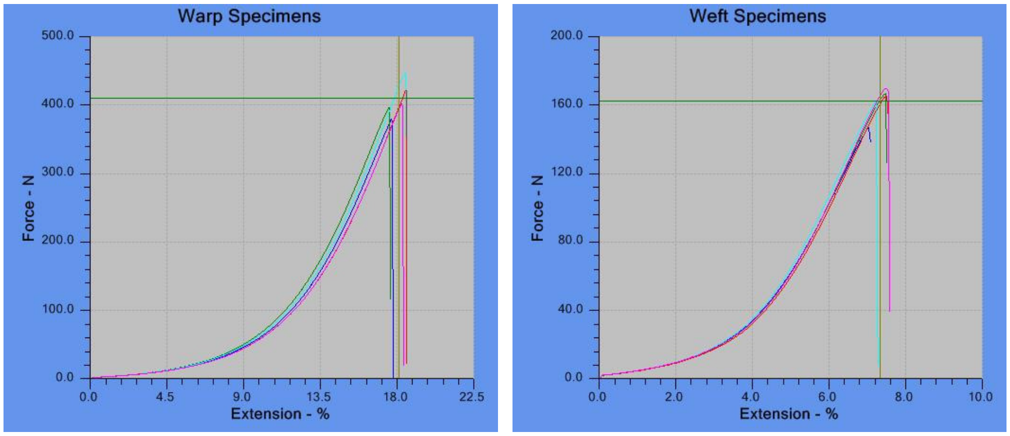


Figure A.8 Tensile strength-extension chart of K1-8 warp and weft directions in first group of samples

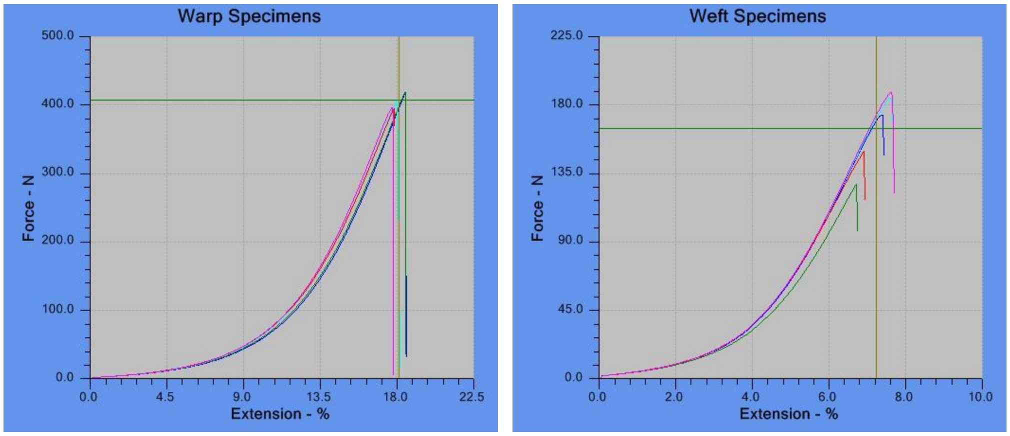


Figure A.9 Tensile strength-extension chart of NK1-8 warp and weft directions in first group of samples

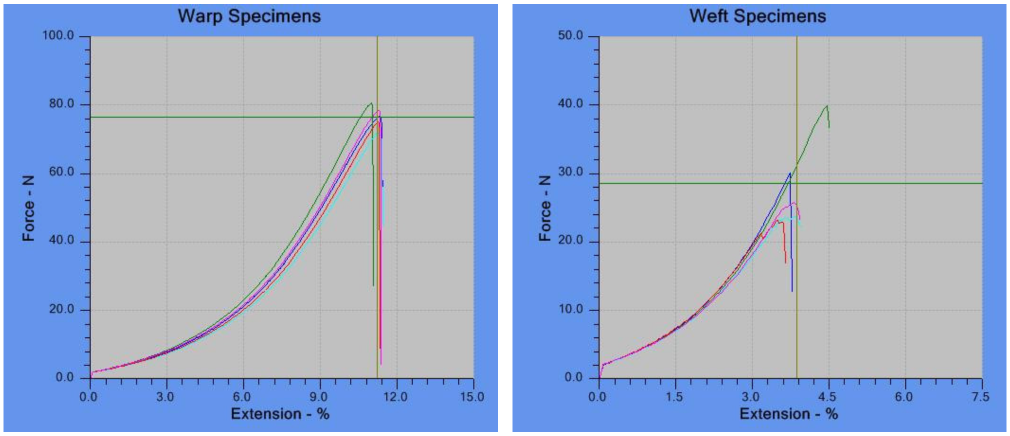


Figure A.10 Tensile strength-extension chart of K1 pH 2 warp and weft directions in first group of samples

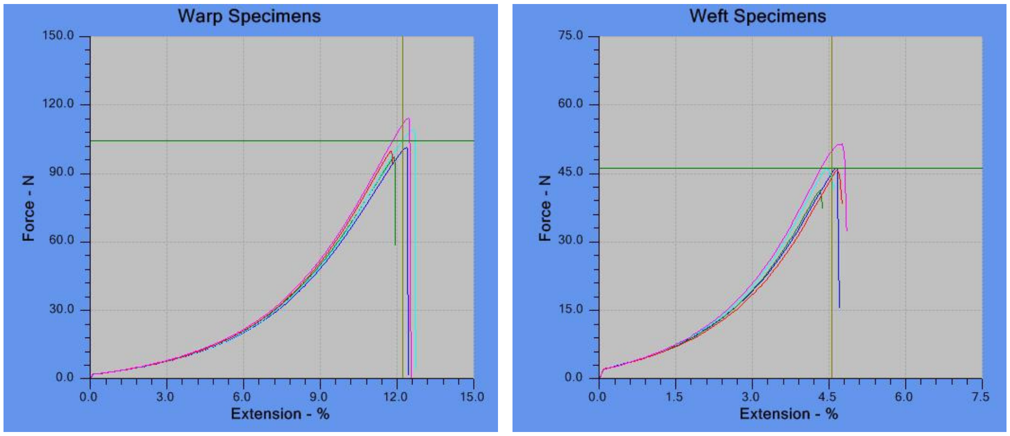


Figure A.11 Tensile strength-extension chart of NK1 pH 2 warp and weft directions in first group of samples

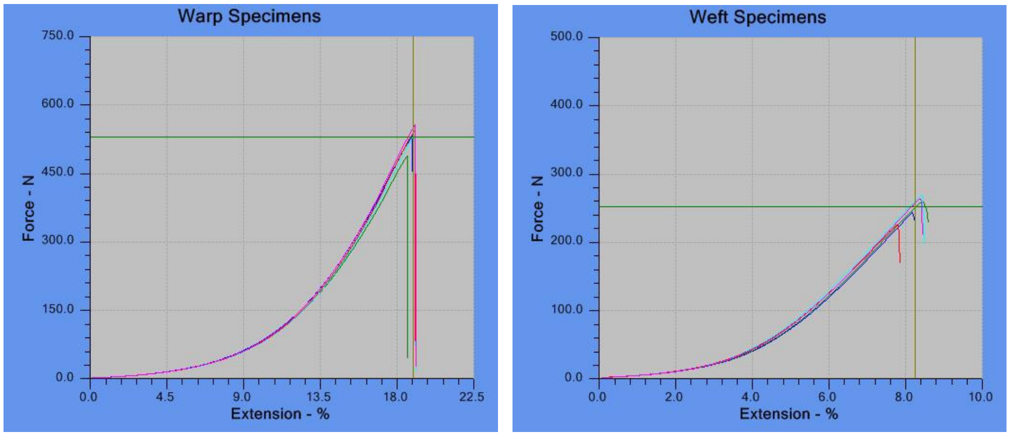


Figure A.12 Tensile strength-extension chart of K1 pH 11 warp and weft directions in first group of samples

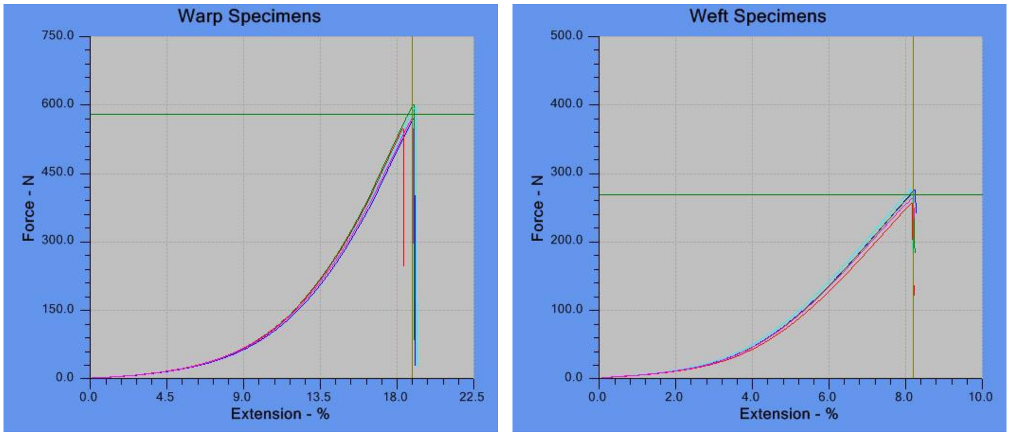


Figure A.13 Tensile strength-extension chart of NK1 pH 11 warp and weft directions in first group of samples

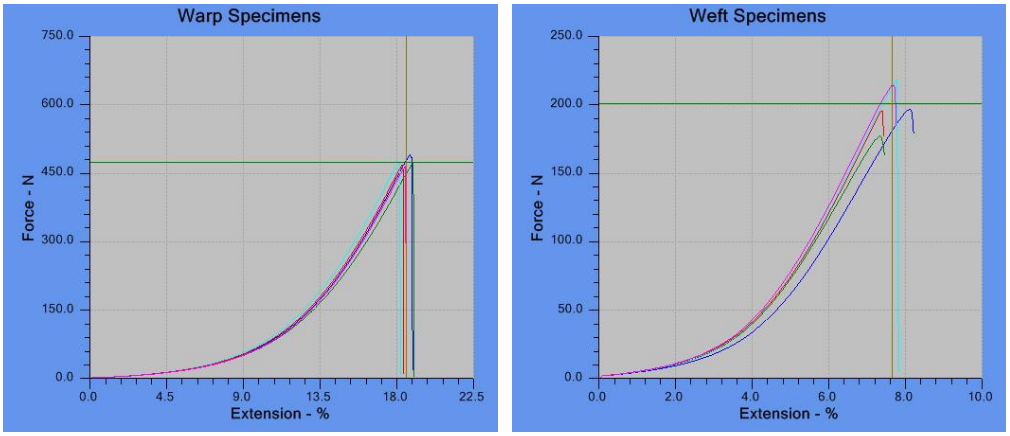


Figure A.14 Tensile strength-extension chart of K1 pH 8 warp and weft directions in first group of samples

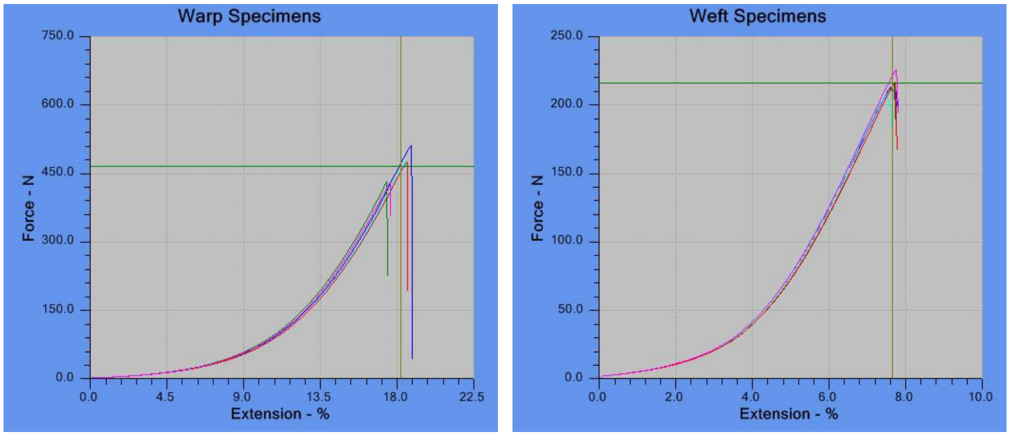


Figure A.15 Tensile strength-extension chart of NK1 pH 8 warp and weft directions in first group of samples

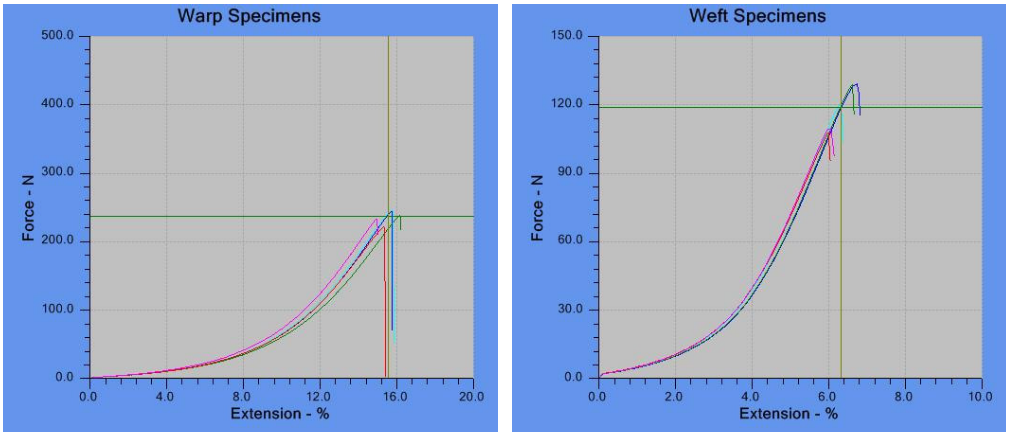


Figure A.16 Tensile strength-extension chart of K3 pH 2 warp and weft directions in first group of samples

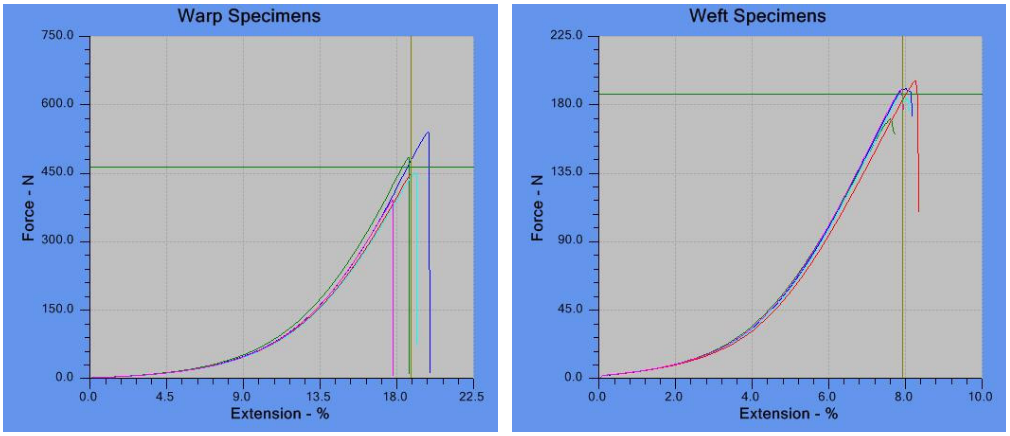
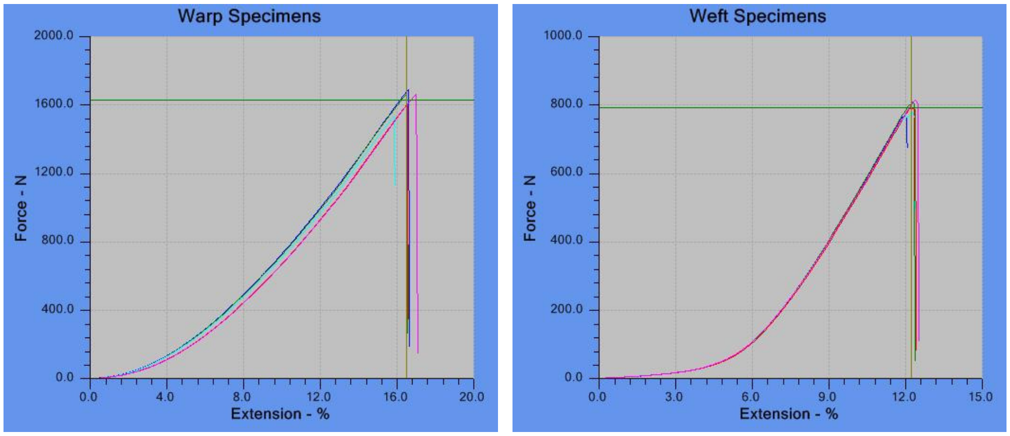
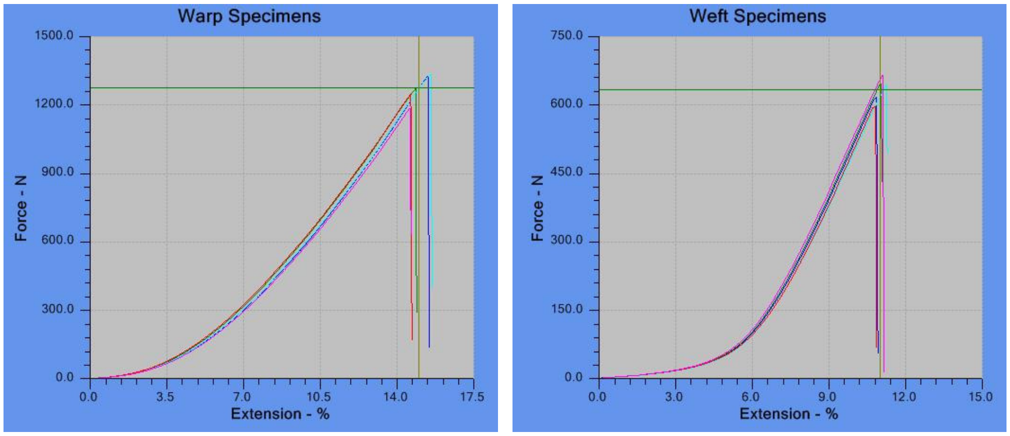


Figure A.17 Tensile strength-extension chart of NK3 pH 2 warp and weft directions in first group of samples


Warp Specimens

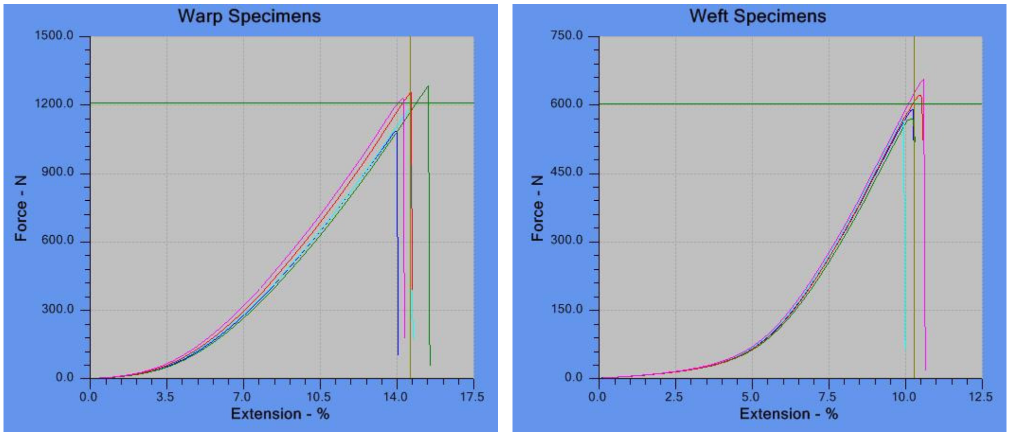
Weft Specimens

Figure A.18 Tensile strength-extension chart of untreated sample warp and weft directions in second group of samples


Warp Specimens

Weft Specimens

Figure A.19 Tensile strength-extension chart of Recipe 1a foam warp and weft directions in second group of samples


Warp Specimens

Weft Specimens

Figure A.20 Tensile strength-extension chart of Recipe 1a nano foam warp and weft directions in second group of samples

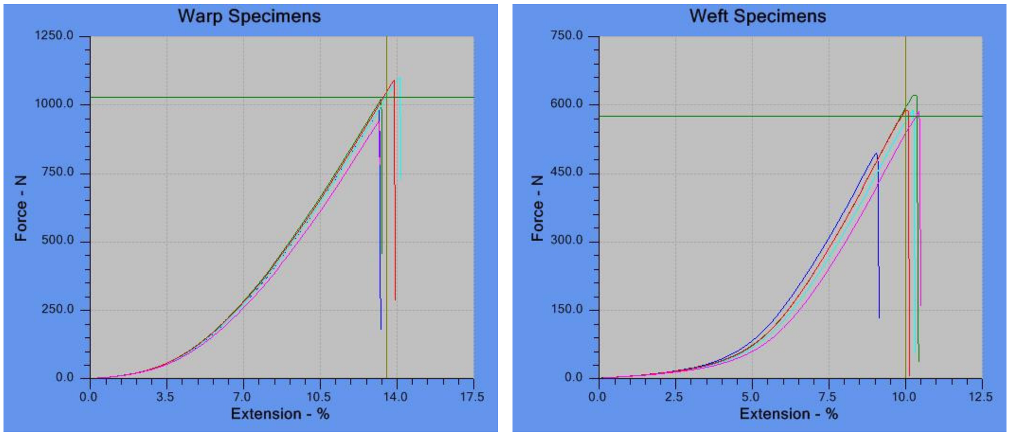


Figure A.21 Tensile strength-extension chart of Recipe 4 foam warp and weft directions in second group of samples

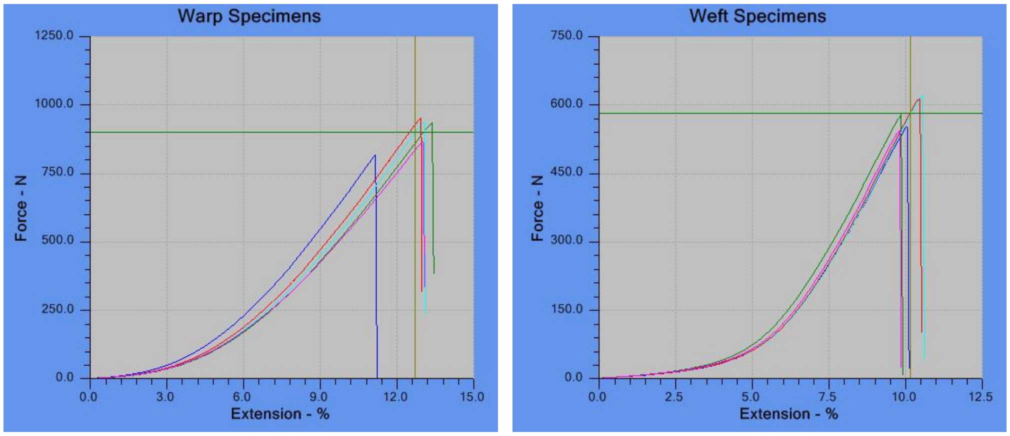


Figure A.22 Tensile strength-extension chart of Recipe 4 nano foam warp and weft directions in second group of samples

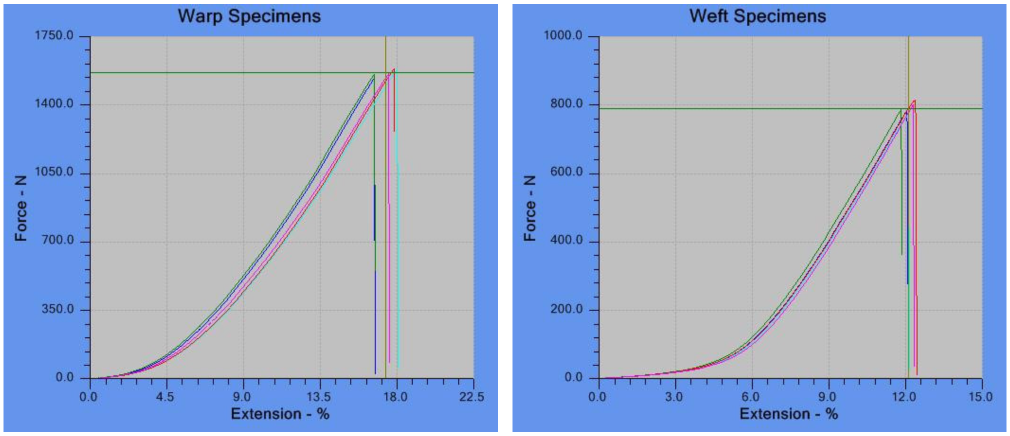


Figure A.23 Tensile strength-extension chart of Recipe 5 foam warp and weft directions in second group of samples

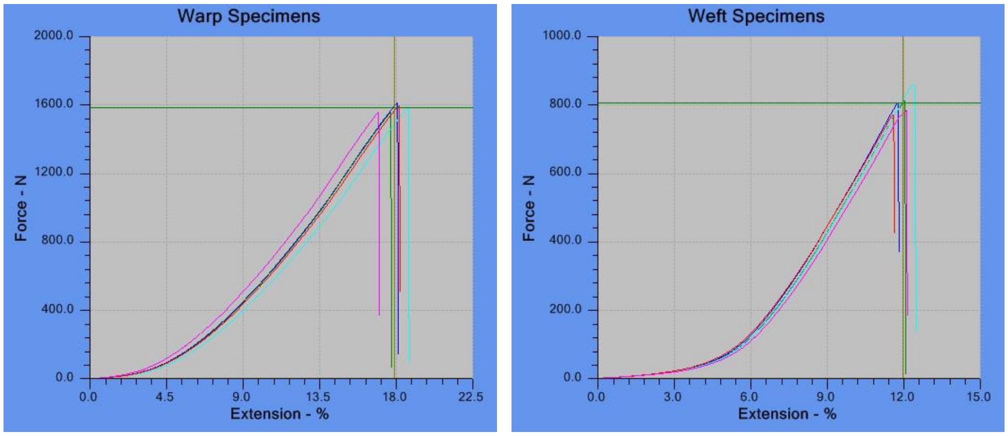


Figure A.24 Tensile strength-extension chart of Recipe 5 nano foam warp and weft directions in second group of samples

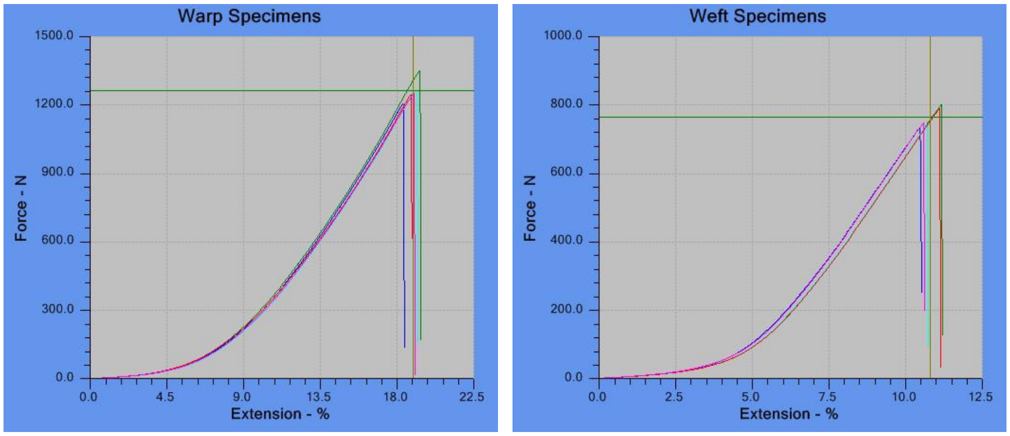


Figure A.25 Tensile strength-extension chart of Recipe 1a pad warp and weft directions in second group of samples

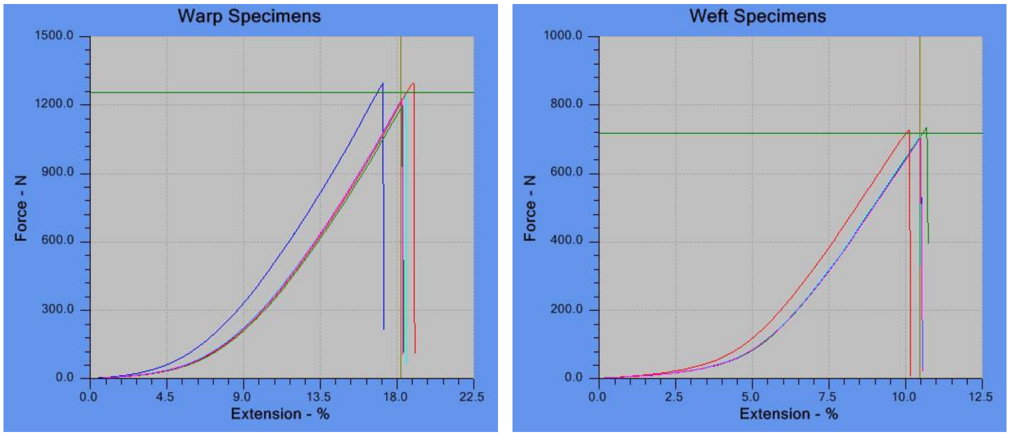
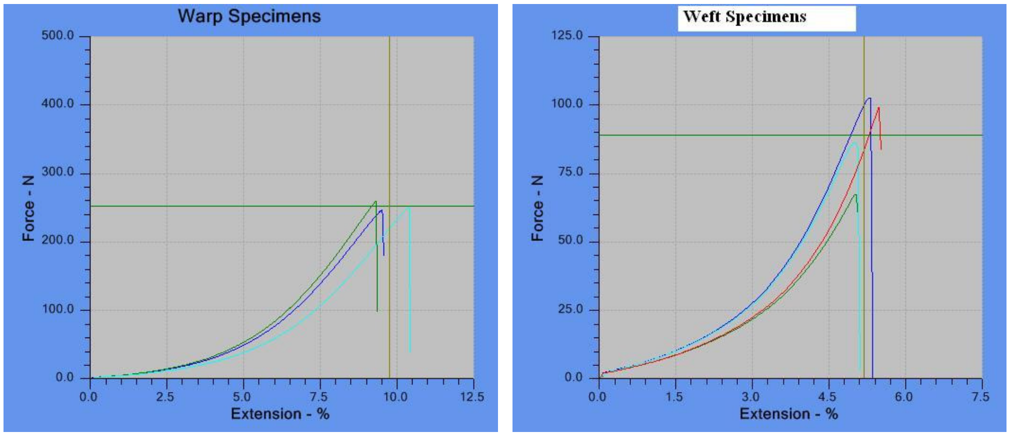
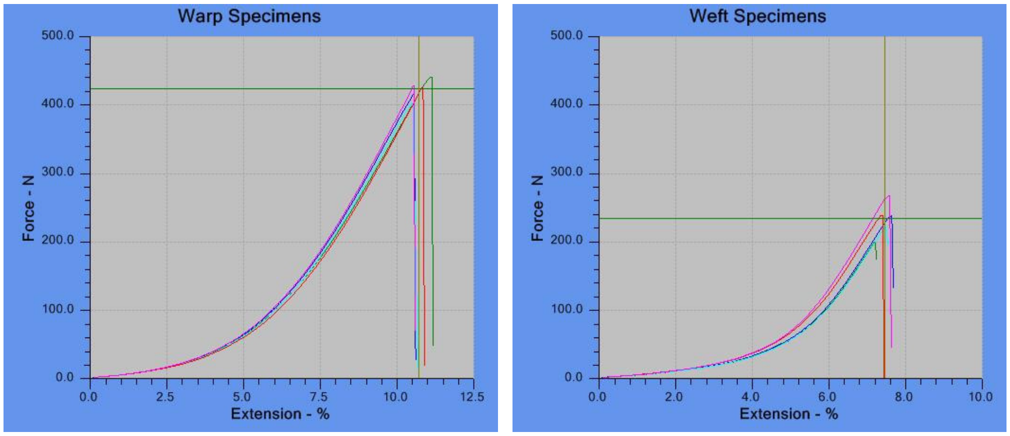


Figure A.26 Tensile strength-extension chart of Recipe 1a nano pad warp and weft directions in second group of samples


Warp Specimens

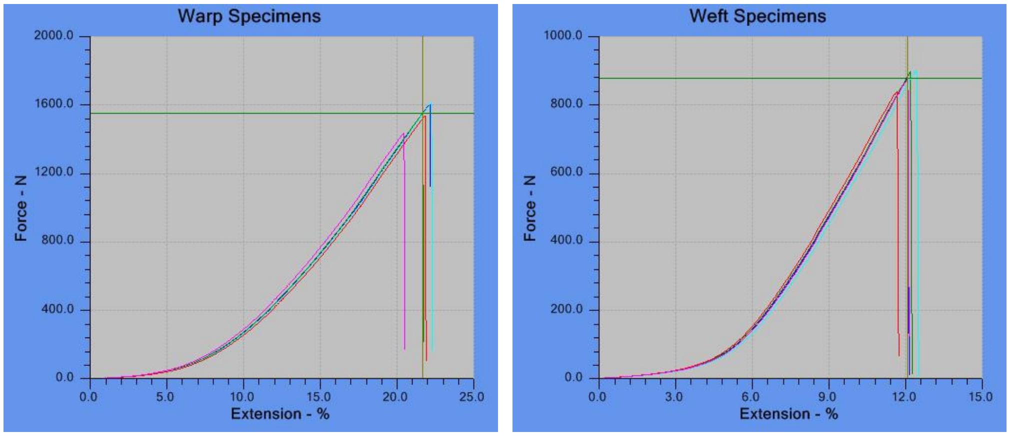
Weft Specimens

Figure A.27 Tensile strength-extension chart of Recipe 4 pad warp and weft directions in second group of samples


Warp Specimens

Weft Specimens

Figure A.28 Tensile strength-extension chart of Recipe 4 nano pad warp and weft directions in second group of samples


Warp Specimens

Weft Specimens

Figure A.29 Tensile strength-extension chart of Recipe 5 pad warp and weft directions in second group of samples

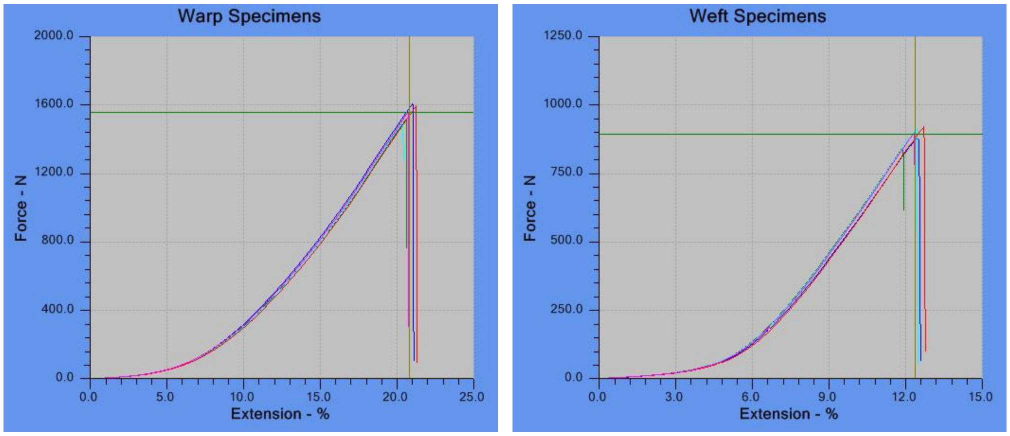


Figure A.30 Tensile strength-extension chart of Recipe 5 nano pad warp and weft directions in second group of samples

APPENDIX B

TEAR STRENGTH OF FIRST GROUP AND SECOND GROUP OF SAMPLES

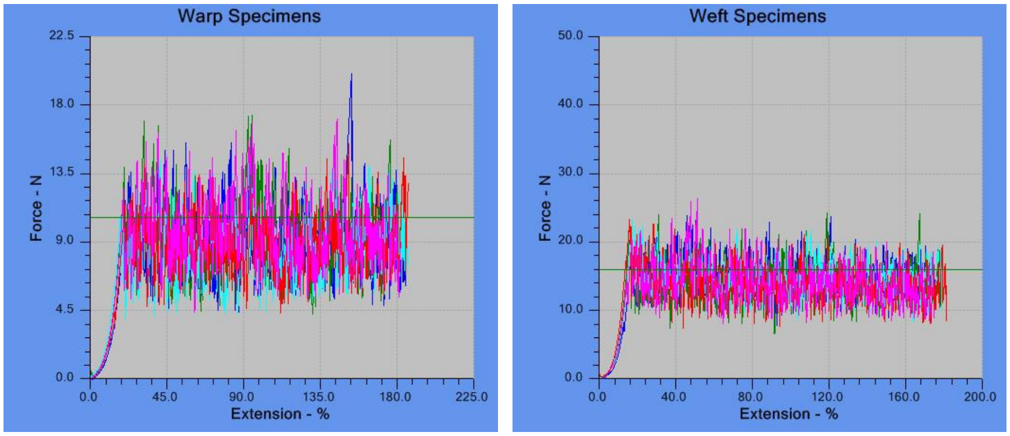


Figure B.1 Tear strength-extension chart of untreated sample warp and weft directions in first group of samples

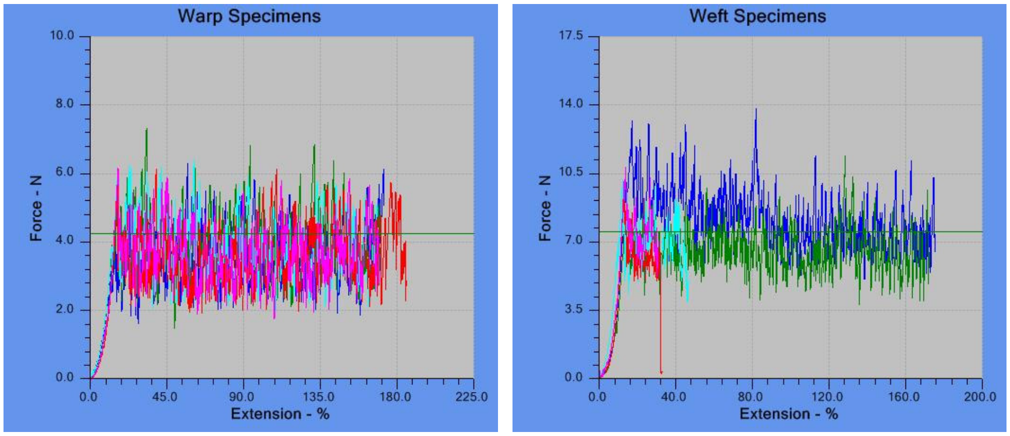


Figure B.2 Tear strength-extension chart of K1 warp and weft directions in first group of samples

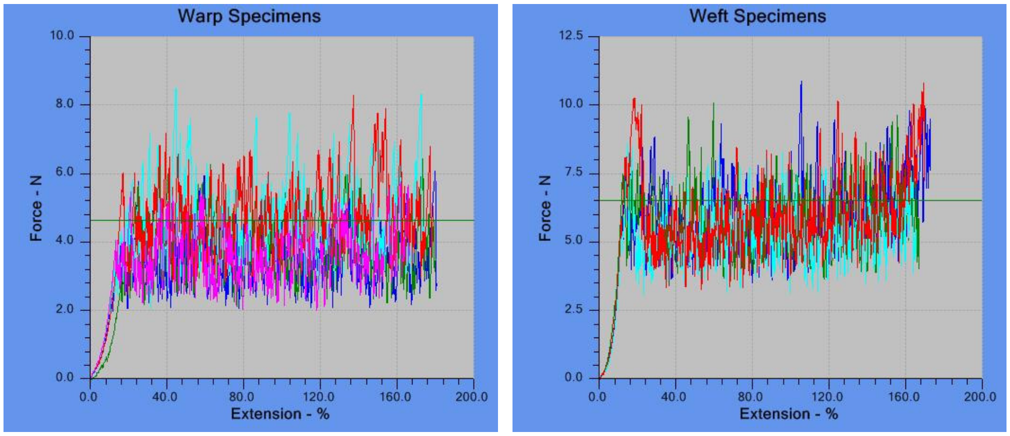


Figure B.3 Tear strength-extension chart of NK1 warp and weft directions in first group of samples

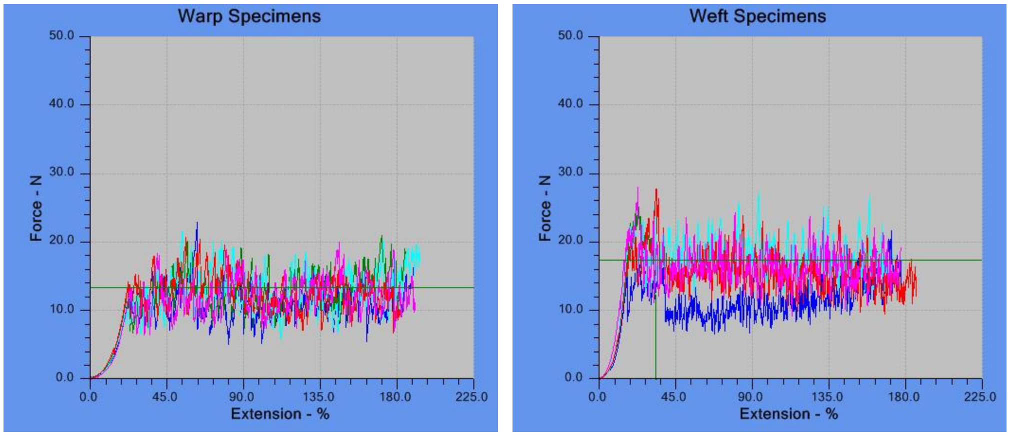


Figure B.4 Tear strength-extension chart of K2 warp and weft directions in first group of samples

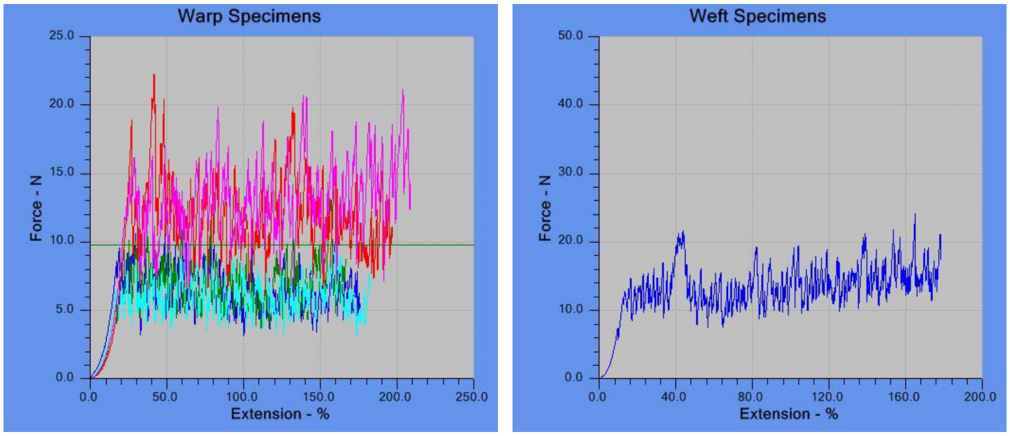


Figure B.5 Tear strength-extension chart of NK2 warp and weft directions in first group of samples

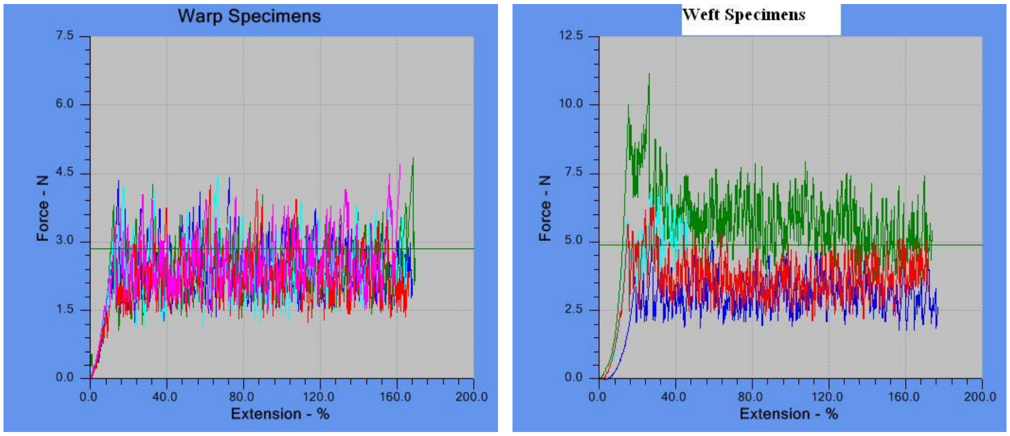


Figure B.6 Tear strength-extension chart of K1-1 warp and weft directions in first group of samples

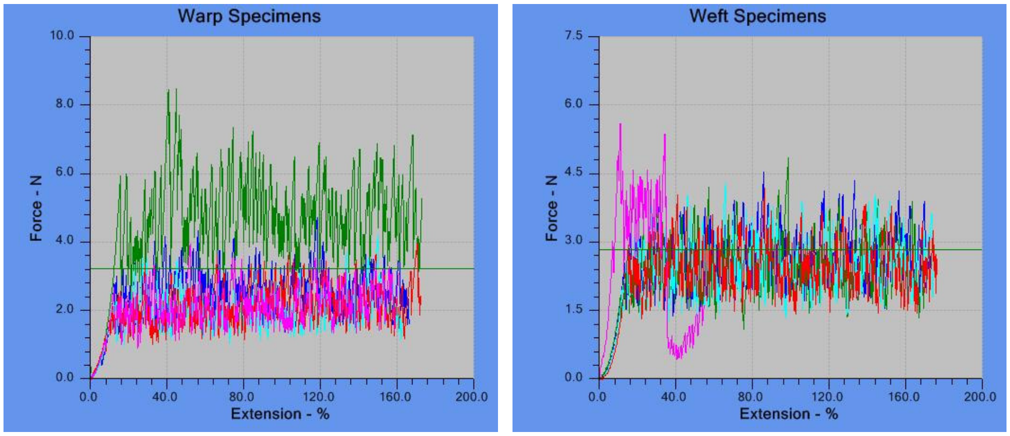


Figure B.7 Tear strength-extension chart of NK1-1 warp and weft directions in first group of samples

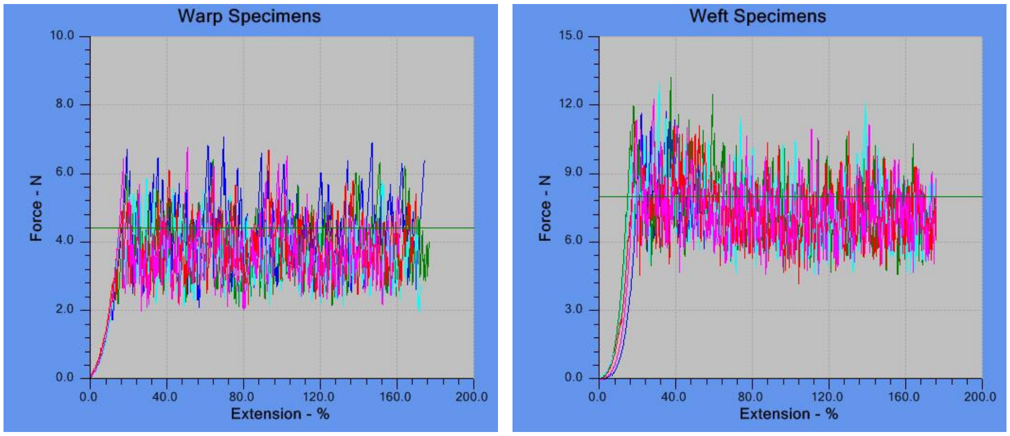


Figure B.8 Tear strength-extension chart of K1-8 warp and weft directions in first group of samples

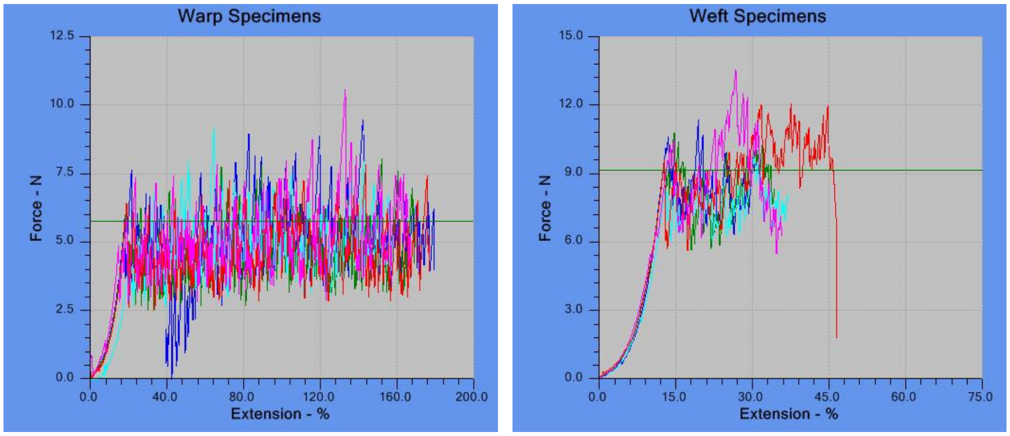


Figure B.9 Tear strength-extension chart of NK1-8 warp and weft directions in first group of samples

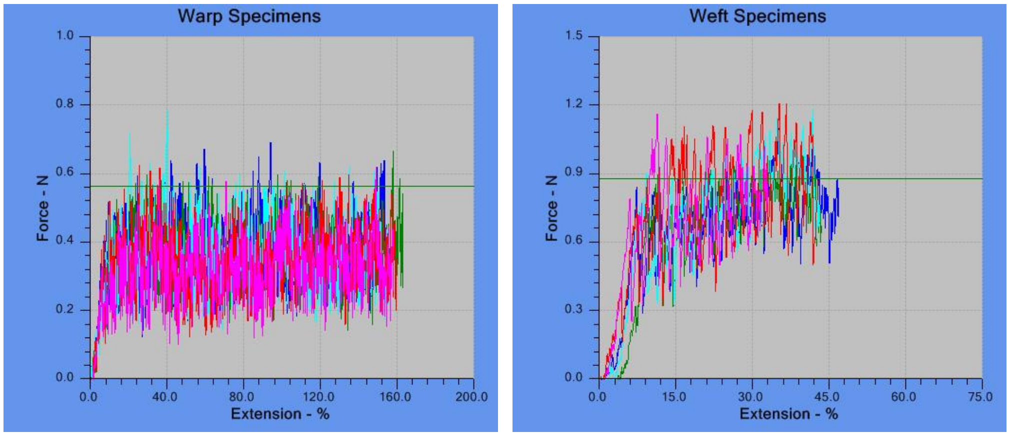


Figure B.10 Tear strength-extension chart of K1 pH 2 warp and weft directions in first group of samples

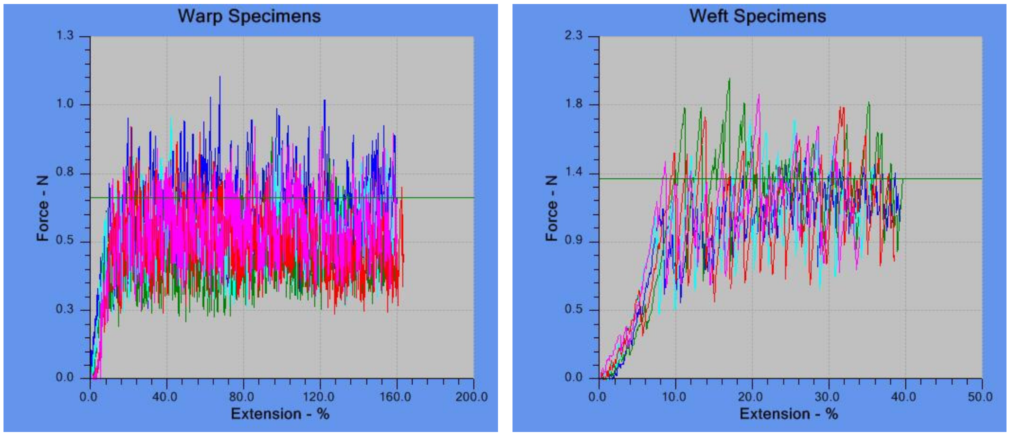


Figure B.11 Tear strength-extension chart of NK1 pH 2 warp and weft directions in first group of samples

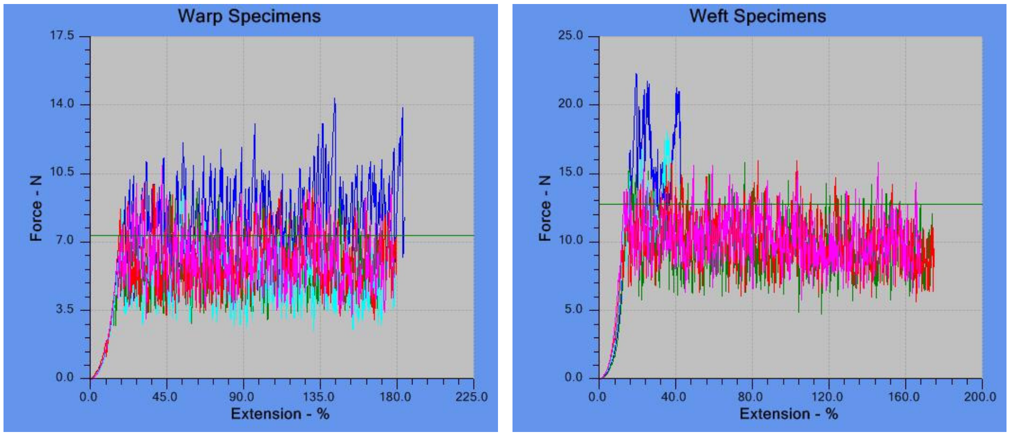


Figure B.12 Tear strength-extension chart of K1 pH 11 warp and weft directions in first group of samples

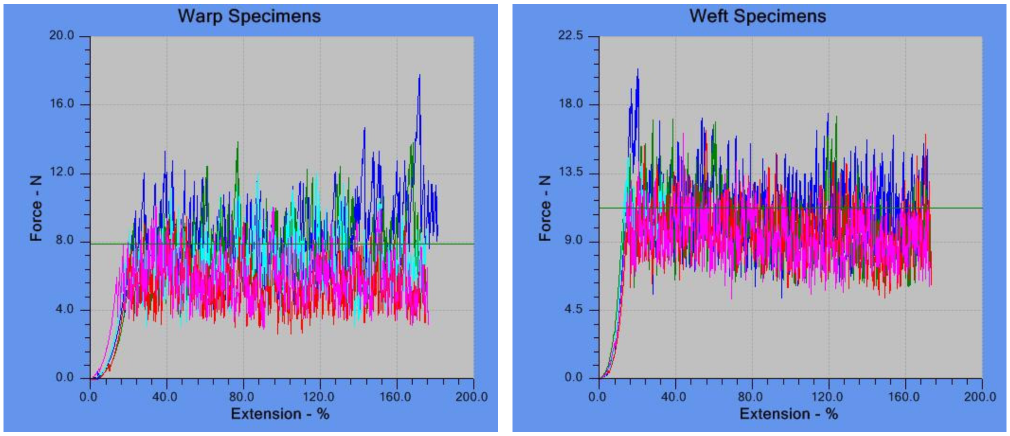


Figure B.13 Tear strength-extension chart of NK1 pH 11 warp and weft directions in first group of samples

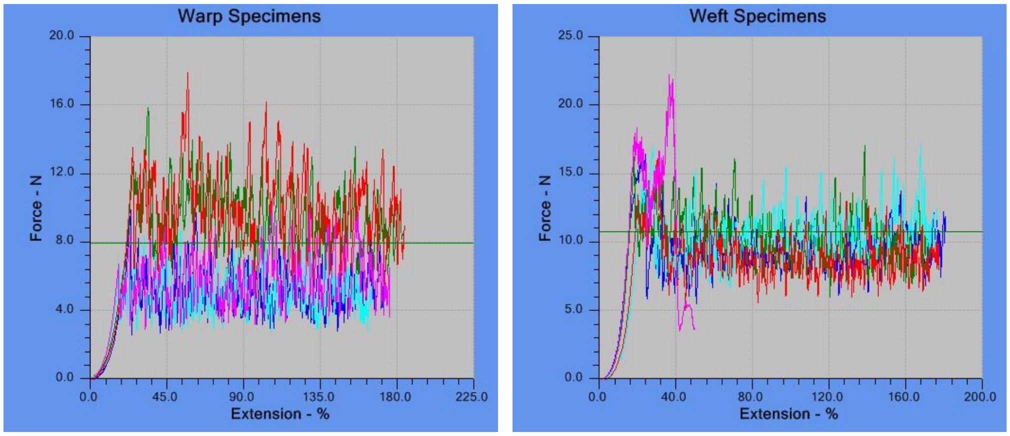


Figure B.14 Tear strength-extension chart of K1 pH 8 warp and weft directions in first group of samples

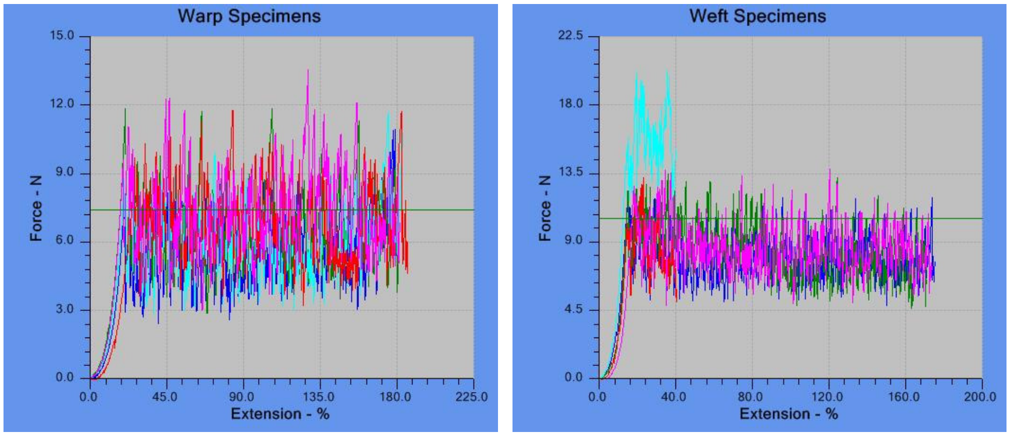


Figure B.15 Tear strength-extension chart of NK1 pH 8 warp and weft directions in first group of samples

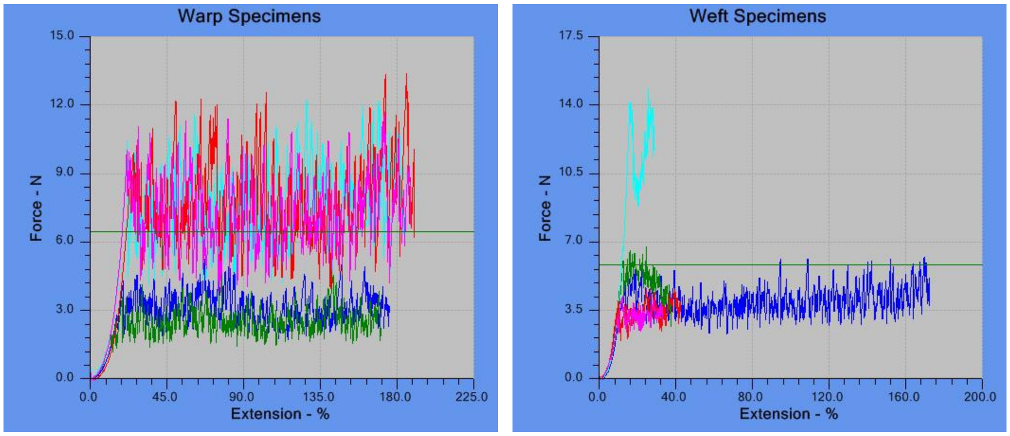


Figure B.16 Tear strength-extension chart of K3 pH 2 warp and weft directions in first group of samples

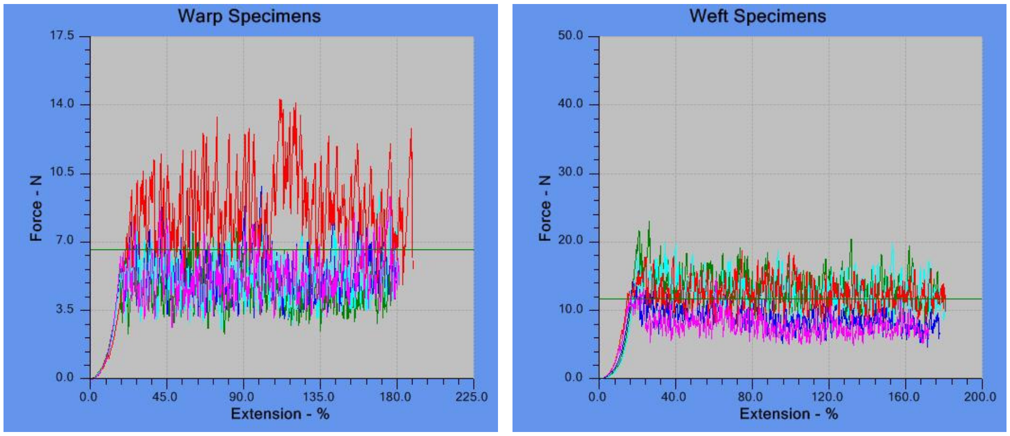


Figure B.17 Tear strength-extension chart of NK3 pH 2 warp and weft directions in first group of samples

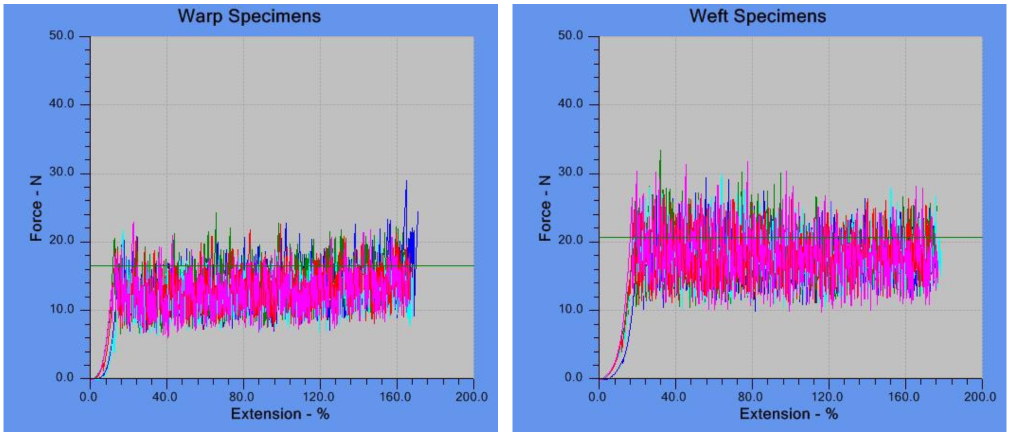


Figure B.18 Tear strength-extension chart of untreated sample warp and weft directions in second group of samples

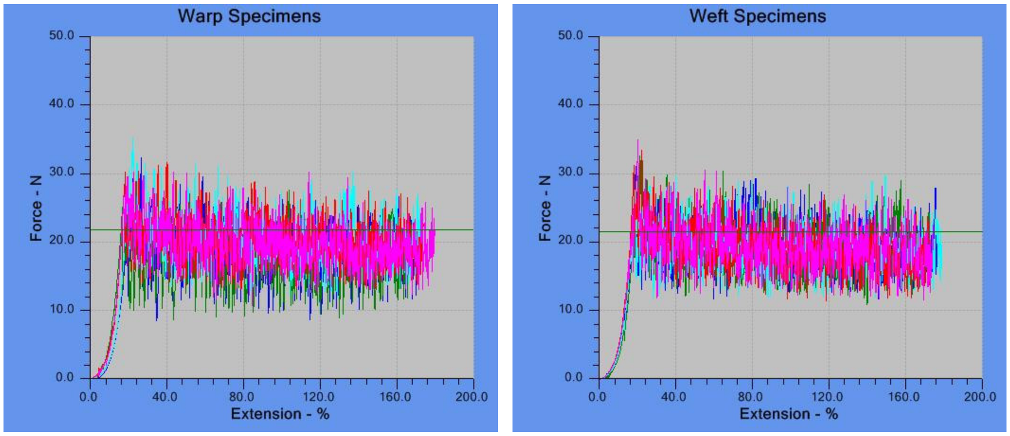


Figure B.19 Tear strength-extension chart of Recipe 1a foam warp and weft directions in second group of samples

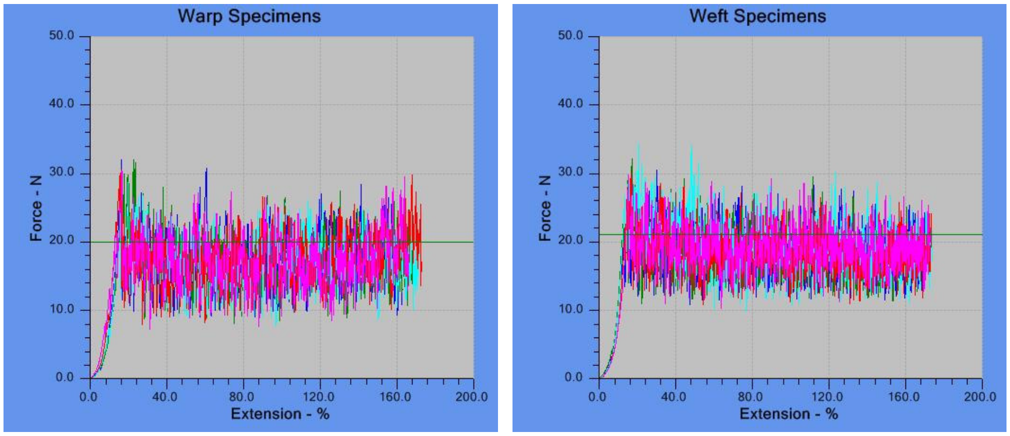


Figure B.20 Tear strength-extension chart of Recipe 1a nano foam warp and weft directions in second group of samples

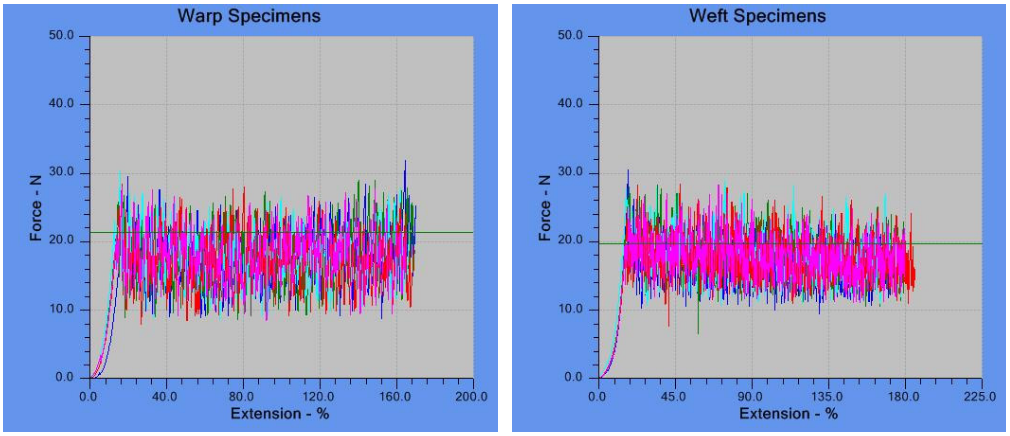


Figure B.21 Tear strength-extension chart of Recipe 4 foam warp and weft directions in second group of samples

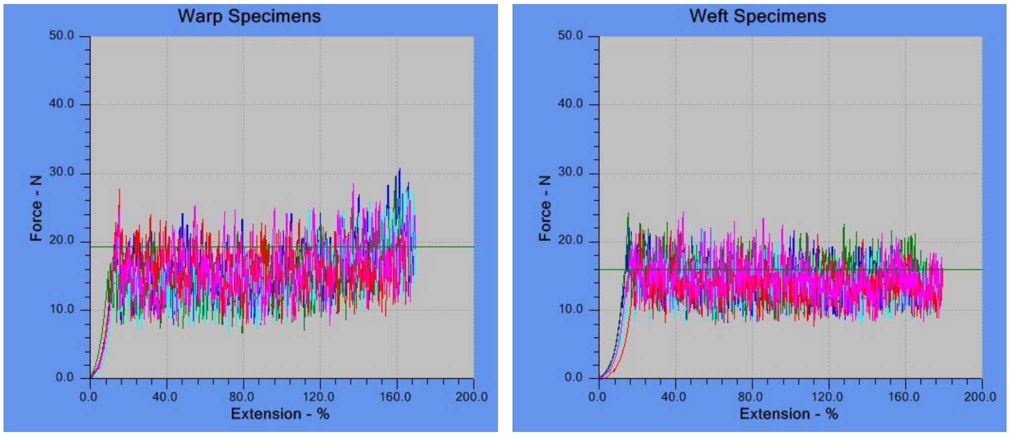


Figure B.22 Tear strength-extension chart of Recipe 4 nano foam warp and weft directions in second group of samples

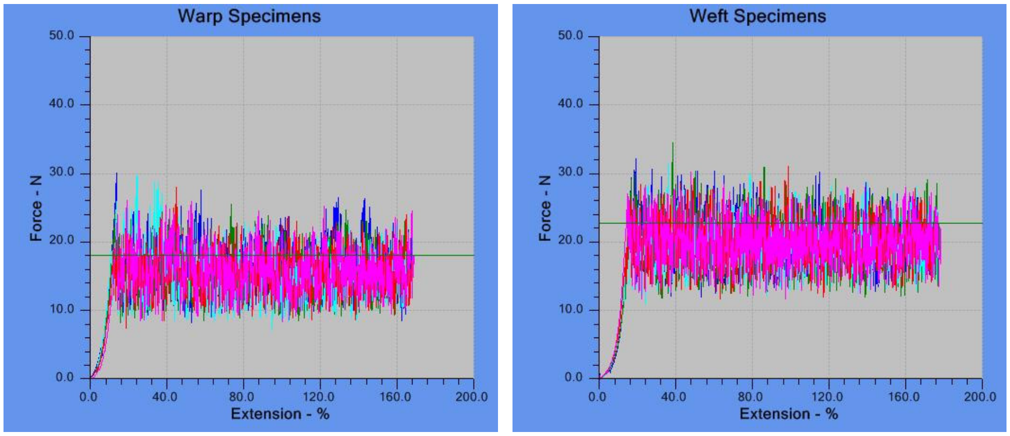


Figure B.23 Tear strength-extension chart of Recipe 5 foam warp and weft directions in second group of samples

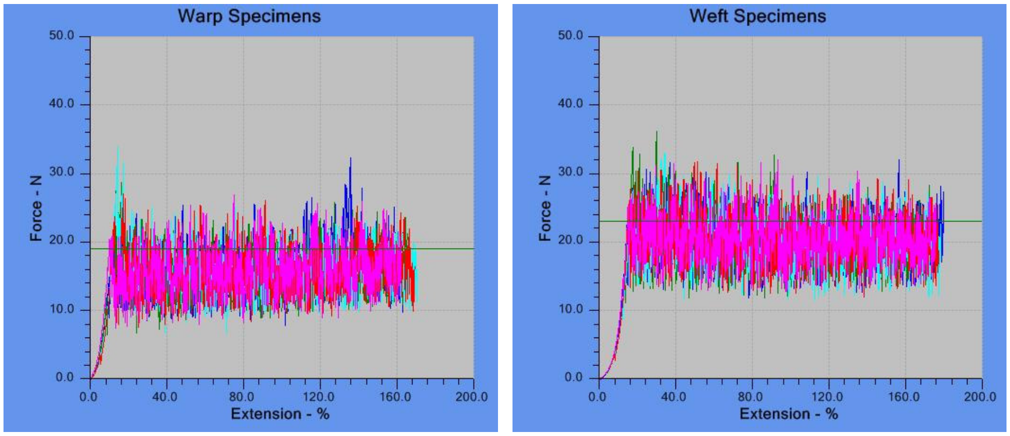


Figure B.24 Tear strength-extension chart of Recipe 5 nano foam warp and weft directions in second group of samples

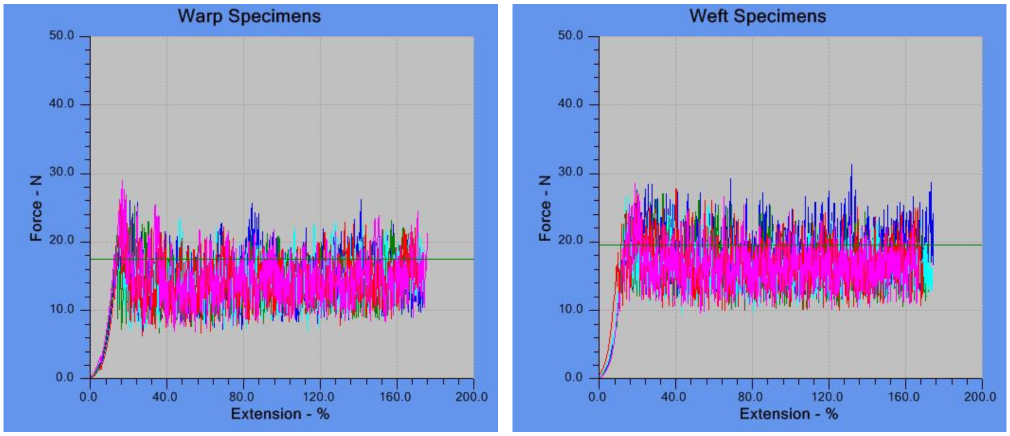


Figure B.25 Tear strength-extension chart of Recipe 1a pad warp and weft directions in second group of samples

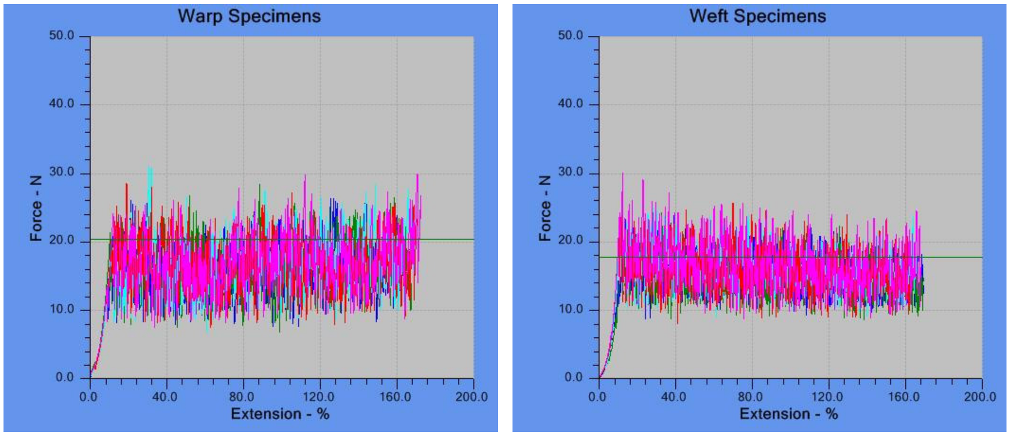


Figure B.26 Tear strength-extension chart of Recipe 1a nano pad warp and weft directions in second group of samples

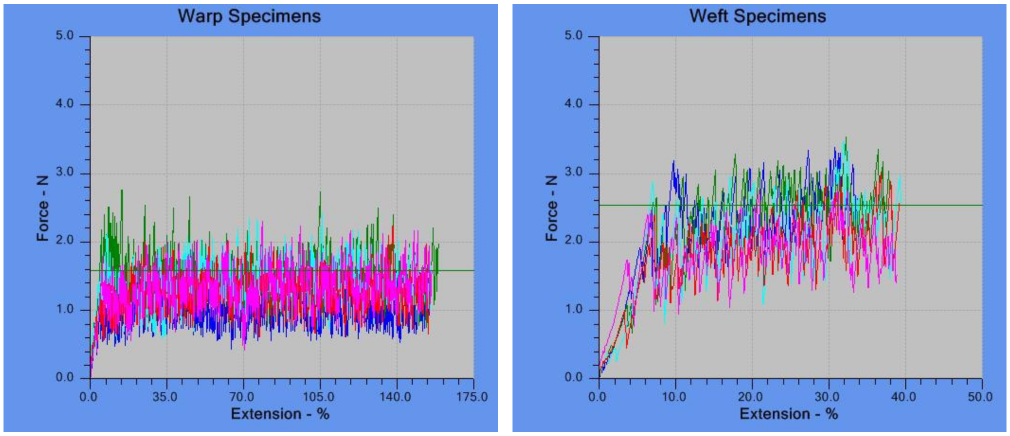


Figure B.27 Tear strength-extension chart of Recipe 4 pad warp and weft directions in second group of samples

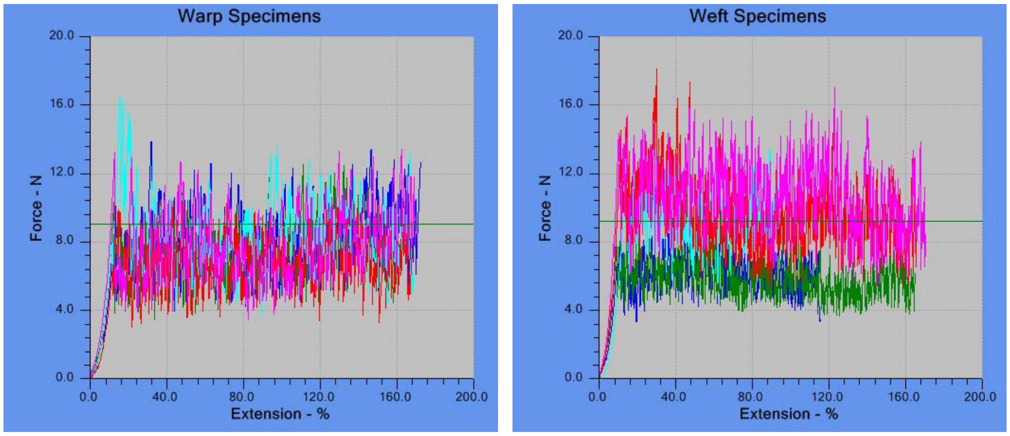


Figure B.28 Tear strength-extension chart of Recipe 4 nano pad warp and weft directions in second group of samples

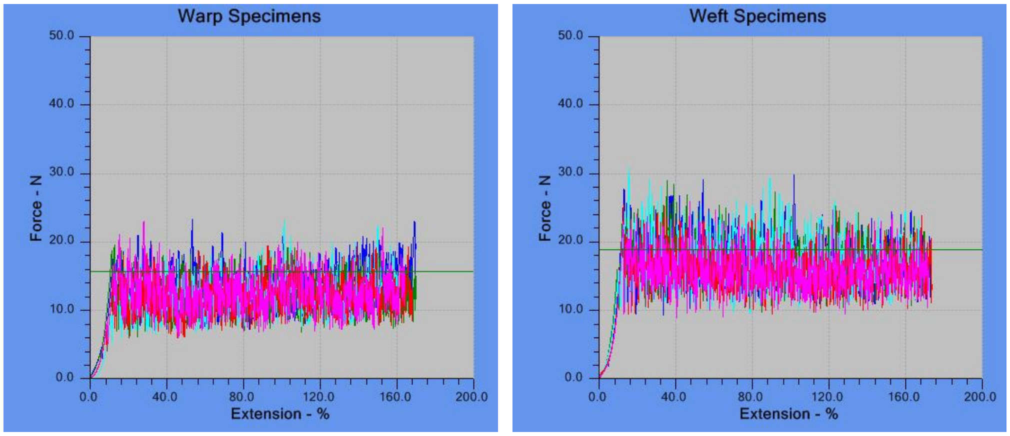


Figure B.29 Tear strength-extension chart of Recipe 5 pad warp and weft directions in second group of samples

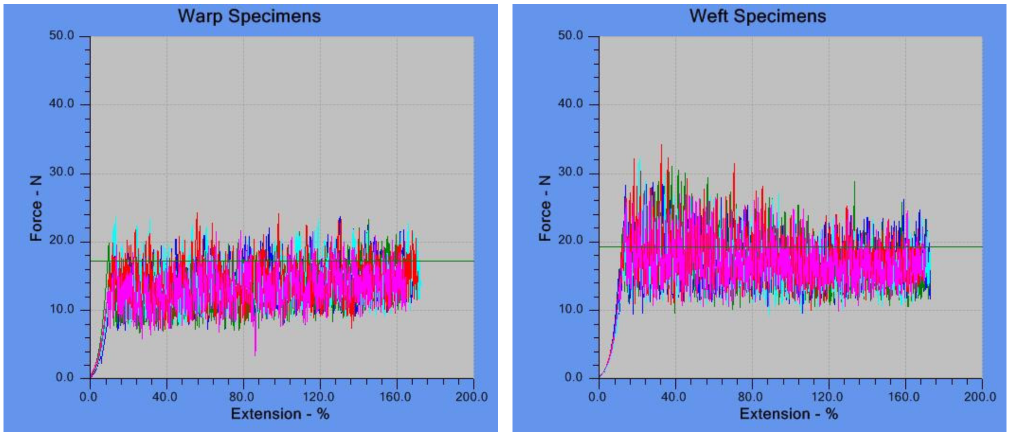


Figure B.30 Tear strength-extension chart of Recipe 5 nano pad warp and weft directions in second group of samples

APPENDIX C

CREASE RECOVERY ANGLES OF FIRST GROUP AND SECOND GROUP OF SAMPLES

Table C.1. Crease recovery angles in warp and weft direction and total angle results in first group of samples

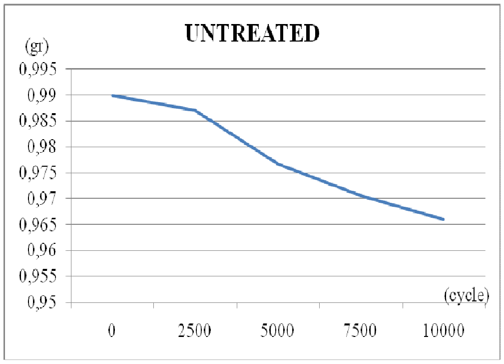
SAMPLES	WARP (°)	WEFT (°)	TOTAL (°)
Untreated	109.25	122.00	231.25
K1	136.50	143.75	280.25
NK1	120.25	157.25	277.50
K2	107.25	155.75	264.25
NK2	98.25	147.75	246.00
K1-1	112.50	157.00	269.50
NK1-1	115.50	153.25	268.75
K1-8	125.00	162.25	287.25
NK1-8	126.25	162.75	289.00
K1 pH2	105.25	153.25	258.50
NK1 pH2	115.25	162.75	278.00
K1 pH11	102.25	143.00	245.25
NK1 pH11	91.75	142.00	233.75
K1 pH8	100.50	145.25	245.75
NK1 pH8	103.25	133.00	236.25
K3 pH2	105.75	146.50	252.25
NK3 pH2	98.00	135.00	233.00

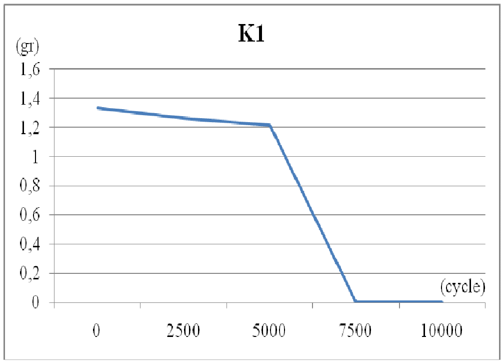
Table C.2. Crease recovery angles in warp and weft direction and total angle results in second group of samples

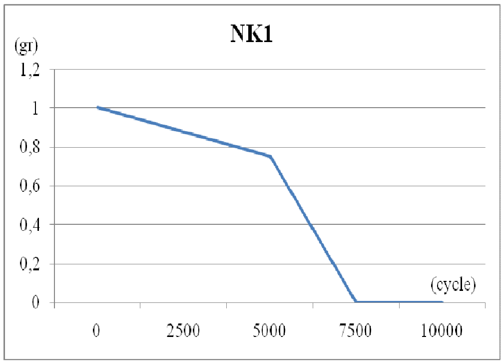
SAMPLES	WARP (°)	WEFT (°)	TOTAL (°)
Untreated	56.50	94.00	150.50
Recipe 1a foam	74.80	120.70	195.50
Recipe 1a nano foam	71.80	117.80	189.60
Recipe 4 foam	77.00	129.80	206.80
Recipe 4 nano foam	79.20	129.20	208.40
Recipe 5 foam	63.30	99.70	163.00
Recipe 5 nano foam	64.30	104.00	168.30
Recipe 1a pad	62.70	114.00	176.70
Recipe 1a nano pad	92.50	113.50	206.00
Recipe 4 pad	85.00	117.50	202.50
Recipe 4 nano pad	99.50	141.00	240.50
Recipe 5 pad	66.80	100.30	167.10
Recipe 5 nano pad	65.30	98.70	164.00

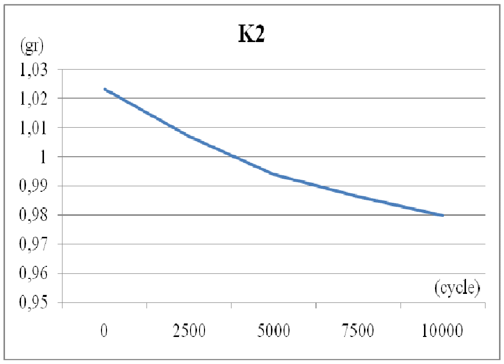
APPENDIX D

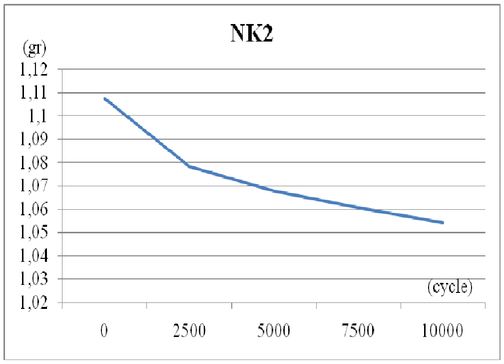
ABRASION RESISTANCE OF FIRST GROUP AND SECOND GROUP OF SAMPLES

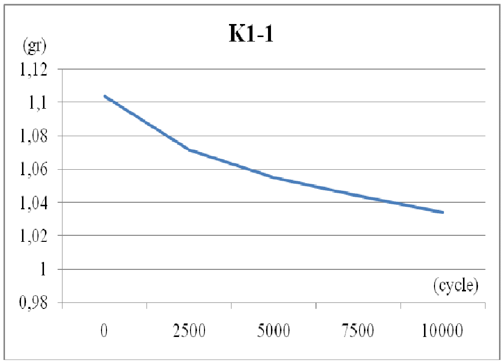


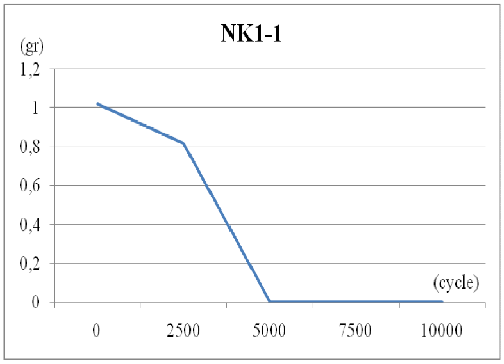








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1
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0,6
0,4
0,2
0
(cycle)
0
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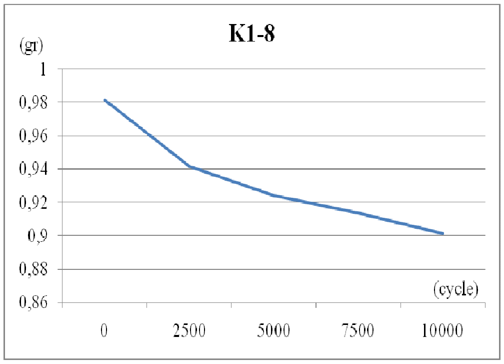
5000
7500
10000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0,86
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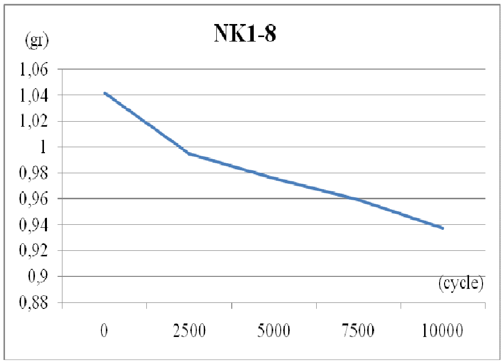
10000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1,04
1,02
1
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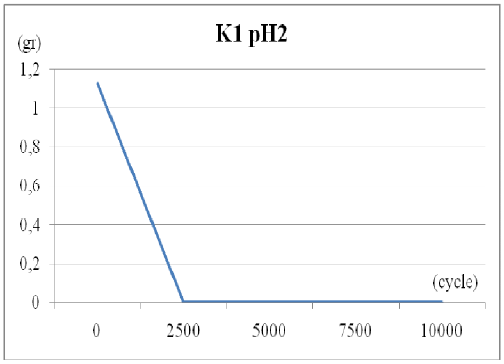
0,94
0,92
0,9
0,88
(cycle)
0
2500
5000
7500
10000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0,4
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(cycle)
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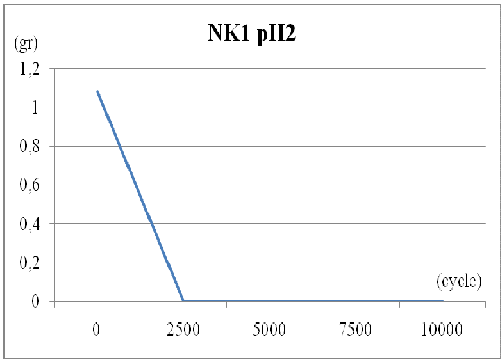
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0,2
0
(cycle)
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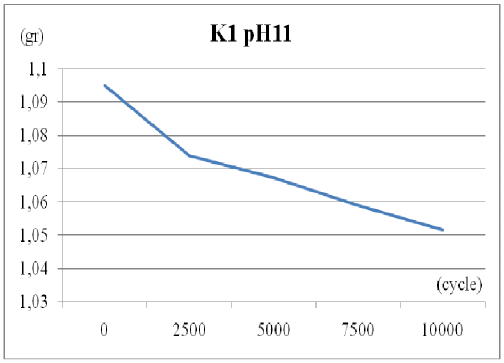
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(cycle)
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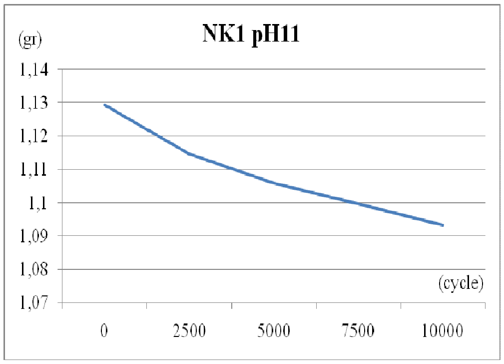
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(cycle)
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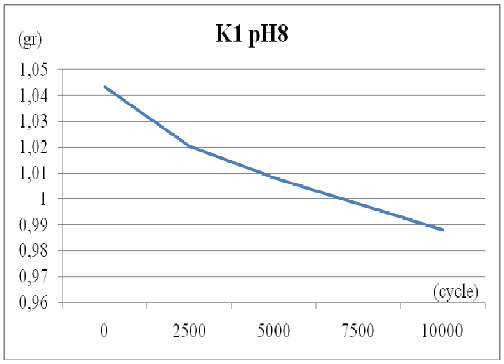
K1 pH8
(gr)
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1
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0,98
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(cycle)
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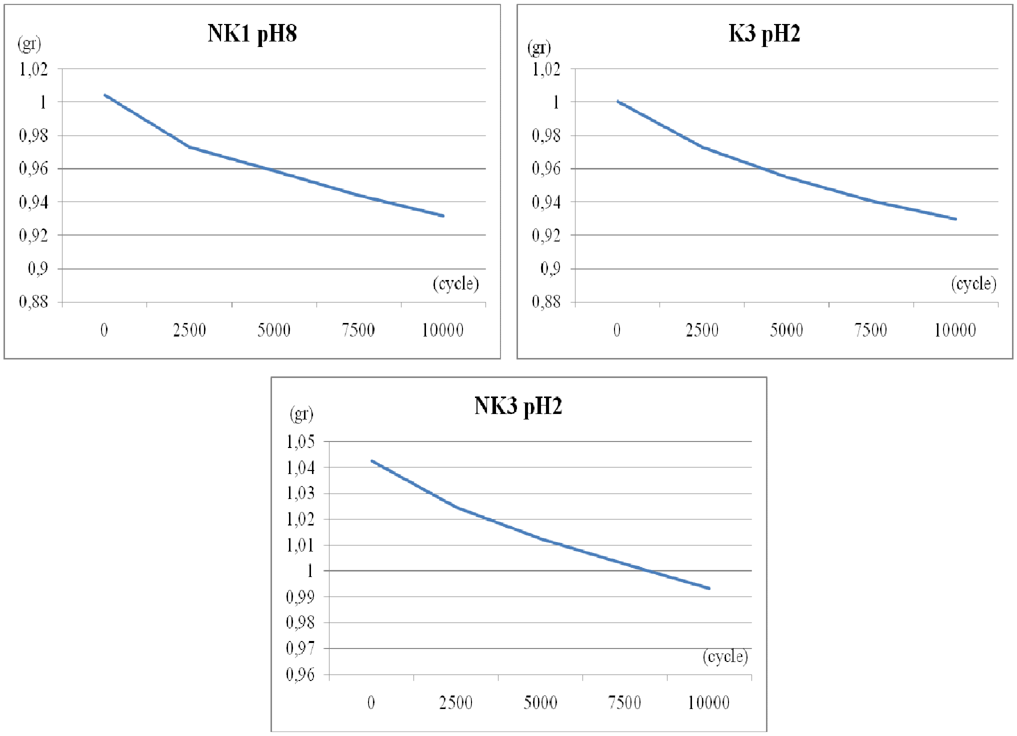
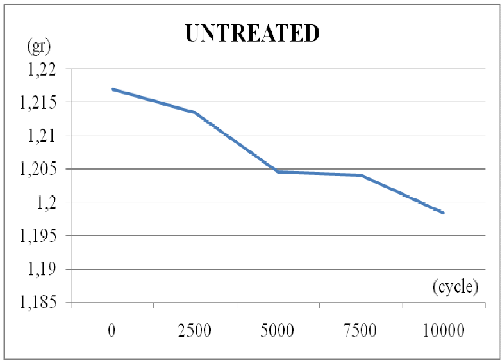
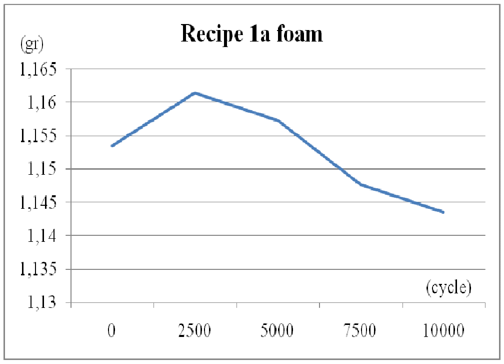


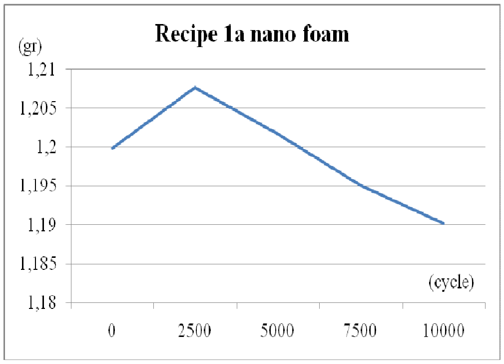
Figure D.1 Mass loss of samples in first group



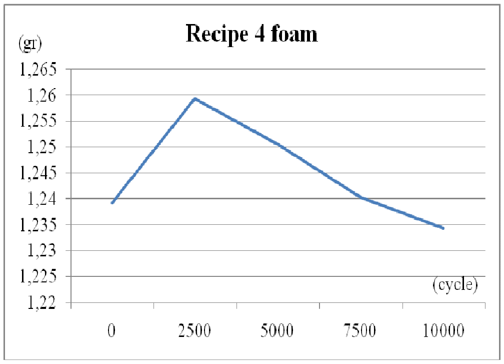
UNTREATED



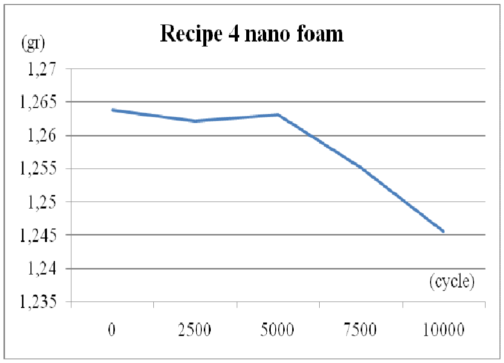
Recipe 1a foam



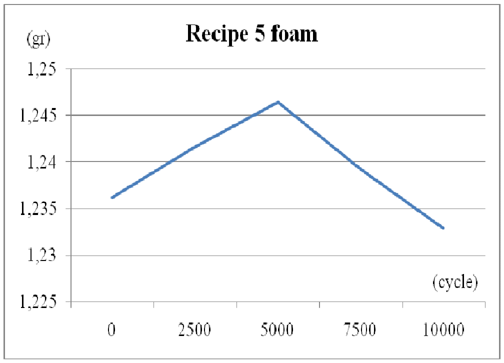
Recipe 1a nano foam



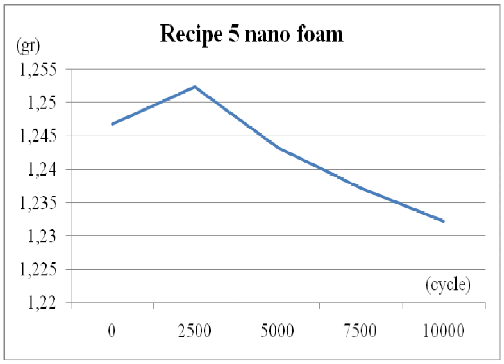
Recipe 4 foam



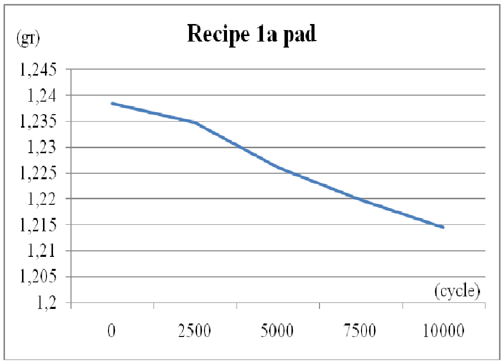
Recipe 4 nano foam



Recipe 5 foam



Recipe 5 nano foam



Recipe 1a pad

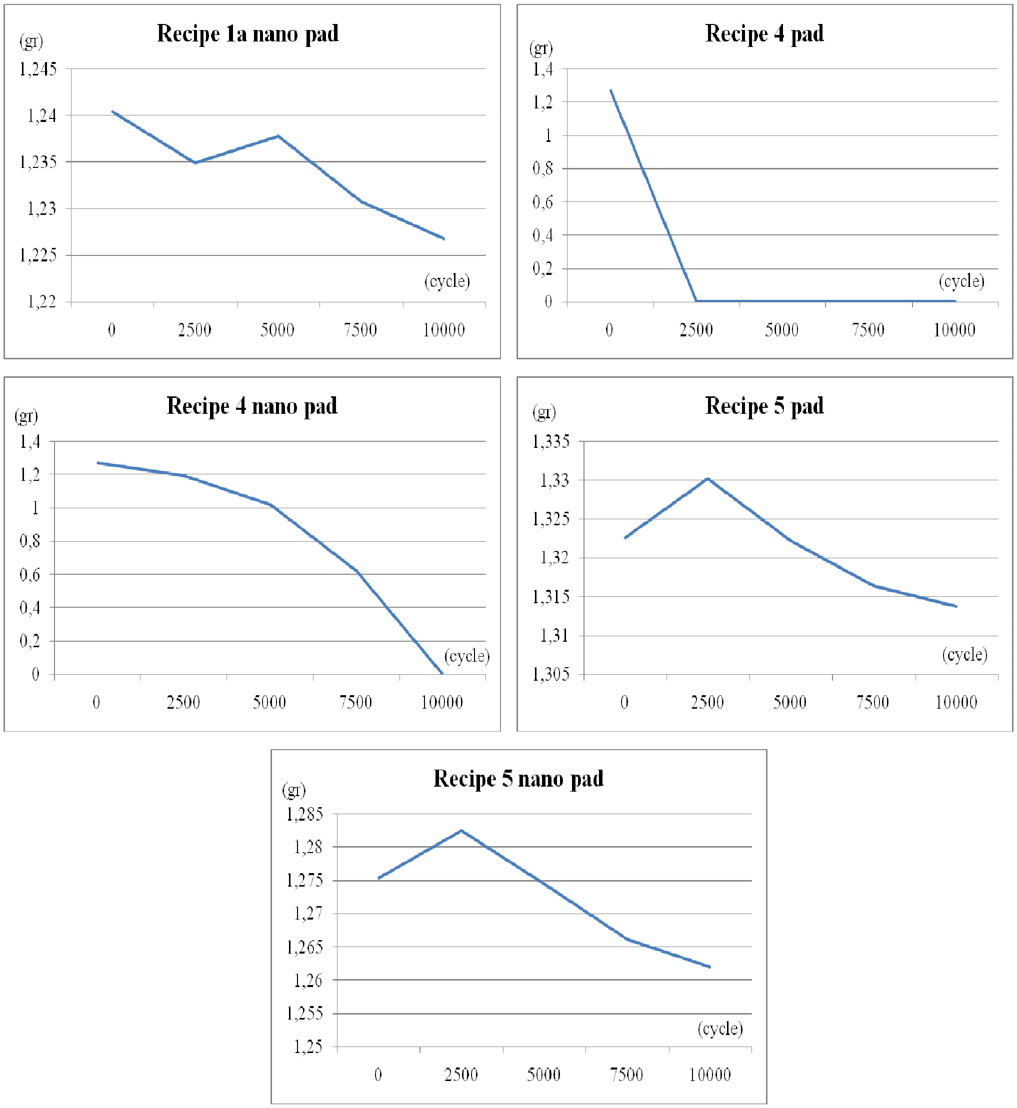


Figure D.30 Mass loss of samples in second group

APPENDIX E

SPECTROPHOTOMETRIC MEASUREMENT OF FIRST GROUP AND SECOND GROUP OF SAMPLES

Table E.1. Whiteness/brightness/yellowness indices and color differences of samples in first group of samples

SAMPLES	**WHITENESS INDICES**	**BRIGHTNESS INDICES**	**YELLOWNESS INDICES**	**COLOR DIFFERENCE**
Untreated	61.73	79.02	7.91	-
K1	55.84	77.50	9.70	1.27
NK1	54.02	73.34	10.20	2.49
K2	63.33	79.59	7.45	0.46
NK2	54.02	74.78	8.48	2.41
K1-1	54.99	76.52	9.40	1.60
NK1-1	50.43	75.72	11.07	2.44
K1-8	60.94	78.54	7.86	0.64
NK1-8	61.51	78.84	7.76	0.58
K1 pH2	-31.18	38.48	26.66	20.33
NK1 pH2	-19.84	49.90	28.04	15.44
K1 pH11	57.71	77.99	8.98	1.22
NK1 pH11	59.06	78.44	8.60	1.06
K1 pH8	67.22	81.07	5.84	1.94
NK1 pH8	61.33	78.07	7.13	1.66
K3 pH2	70.09	80.41	4.35	2.49
NK3 pH2	75.04	82.57	3.03	3.27

Table E.2. Whiteness/brightness/yellowness indices and color differences of samples in second group of samples

SAMPLES	WHITENESS INDICES	BRIGHTNESS INDICES	YELLOWNESS INDICES	COLOR DIFFERENCE
Untreated	73.08	79.51	2.97	-
Recipe 1a foam	74.06	79.38	2.41	0.48
Recipe 1a nano foam	72.66	79.04	2.90	0.35
Recipe 4 foam	72.21	79.17	3.15	0.22
Recipe 4 nano foam	74.11	78.75	2.08	0.98
Recipe 5 foam	71.70	78.83	3.23	0.38
Recipe 5 nano foam	31.92	68.74	15.21	7.81
Recipe 1a pad	71.18	78.99	3.62	0.38
Recipe 1a nano pad	72.52	79.26	3.09	0.14
Recipe 4 pad	25.31	63.17	16.51	8.55
Recipe 4 nano pad	67.02	77.84	4.92	1.21
Recipe 5 pad	70.06	78.23	3.75	0.61
Recipe 5 nano pad	48.56	74.08	10.64	5.12

APPENDIX F

MULTIAXIAL GRAPHS DRAWN BY MATLAB FOR FIRST GROUP AND SECOND GROUP OF SAMPLES

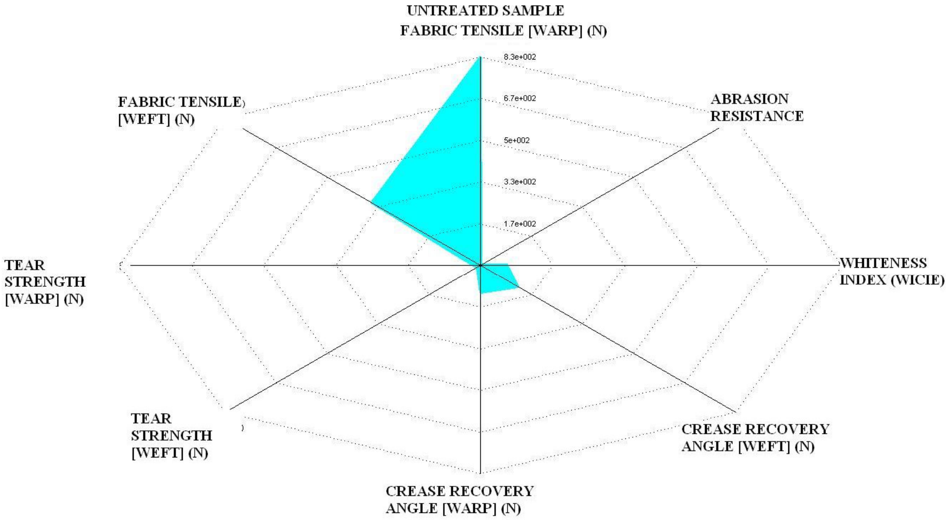


Figure F.1 Multiaxial graph of untreated sample in first group of samples

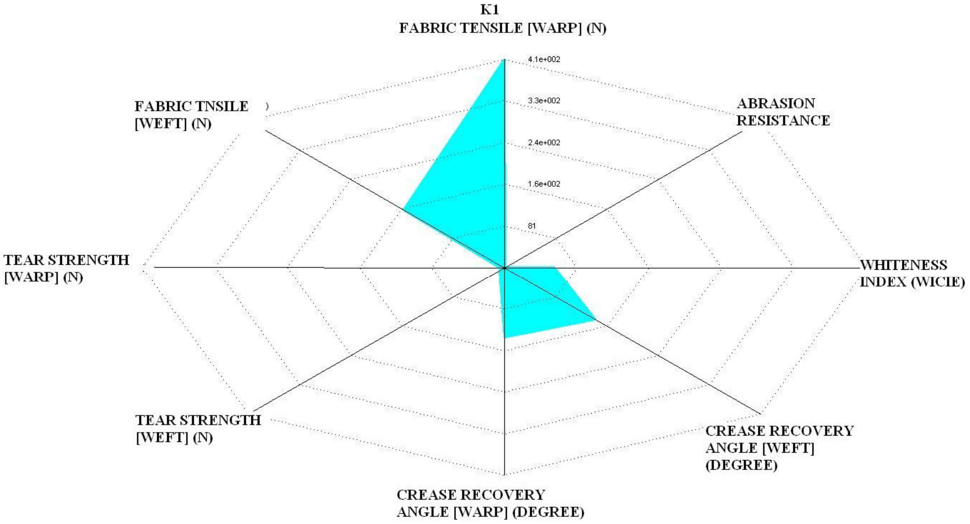


Figure F.2 Multiaxial graph of K1 in first group of samples

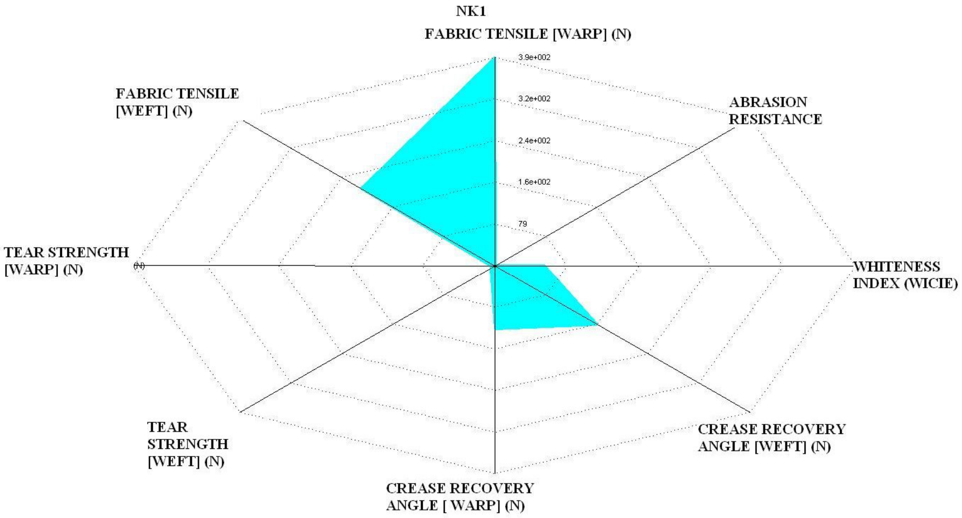


Figure F.3 Multiaxial graph of NK1 in first group of samples

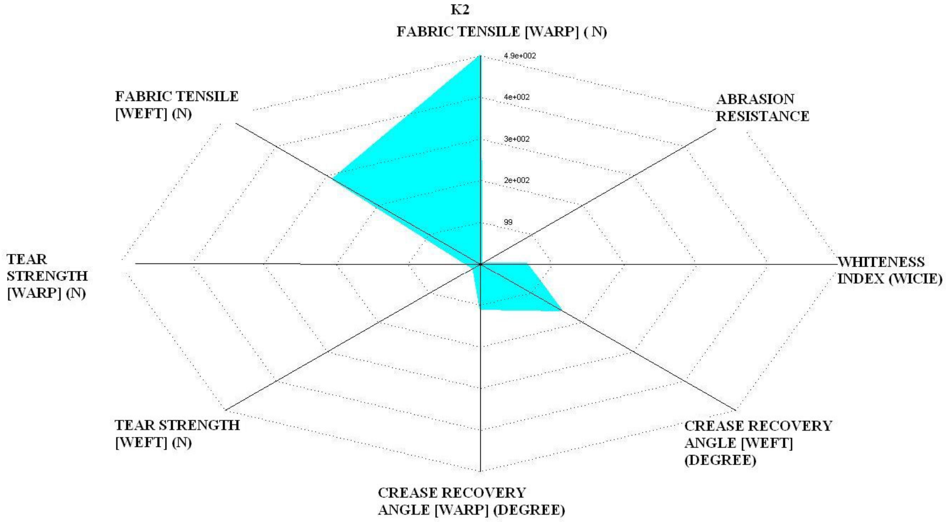


Figure F.4 Multiaxial graph of K2 in first group of samples

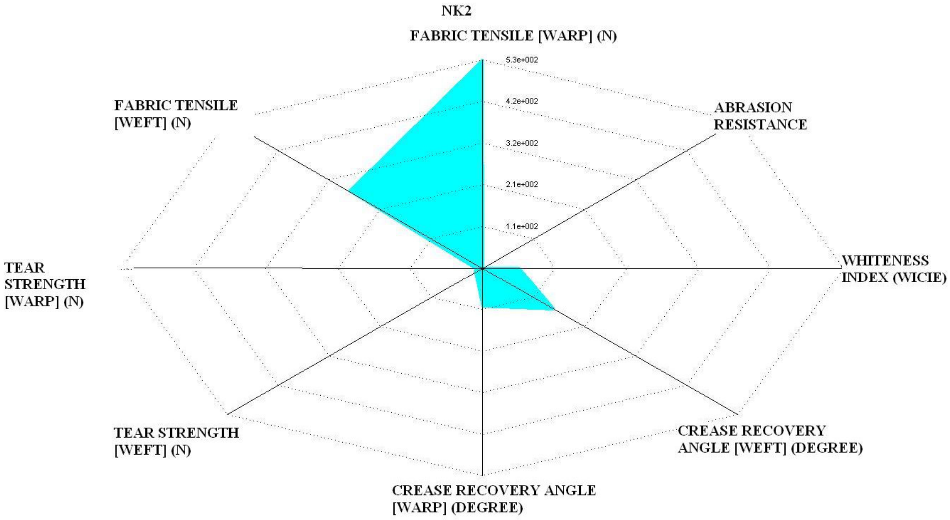


Figure F.5 Multiaxial graph of NK2 in first group of samples

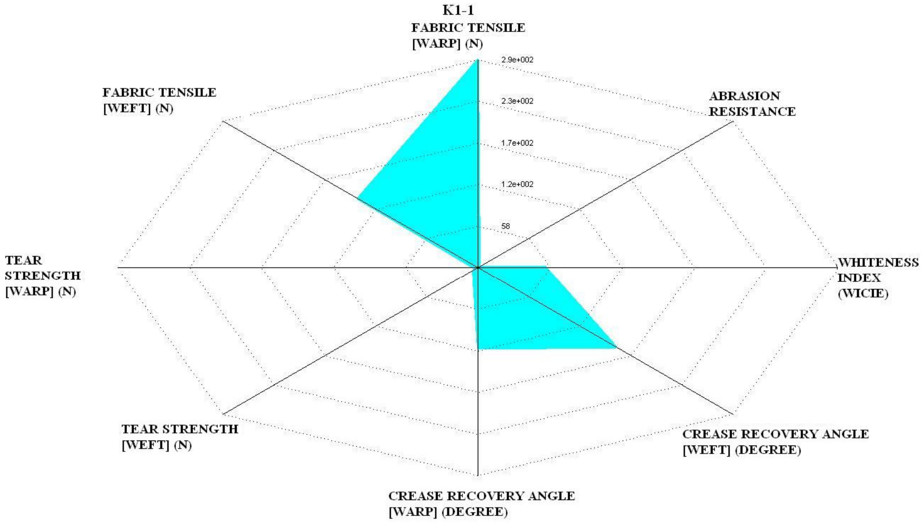


Figure F.6 Multiaxial graph of K1-1 in first group of samples

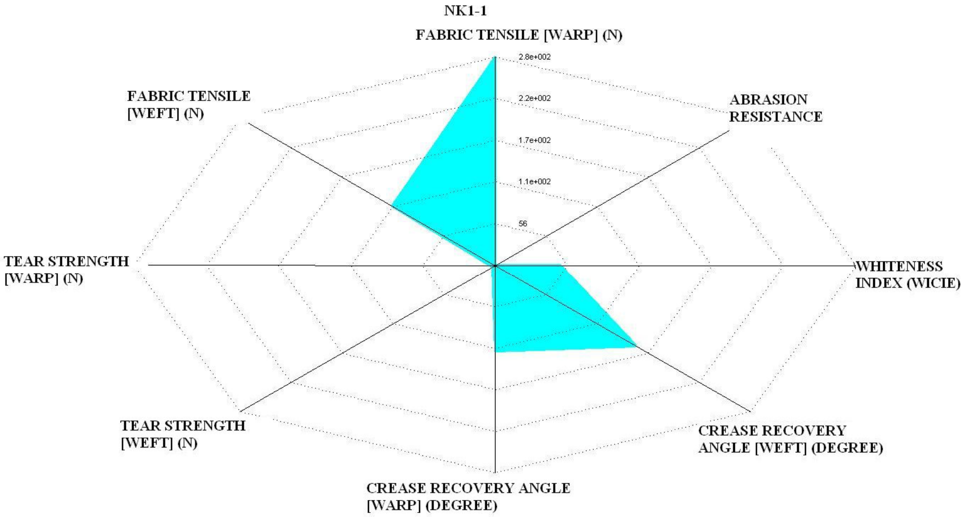


Figure F.7 Multiaxial graph of NK1-1 in first group of samples

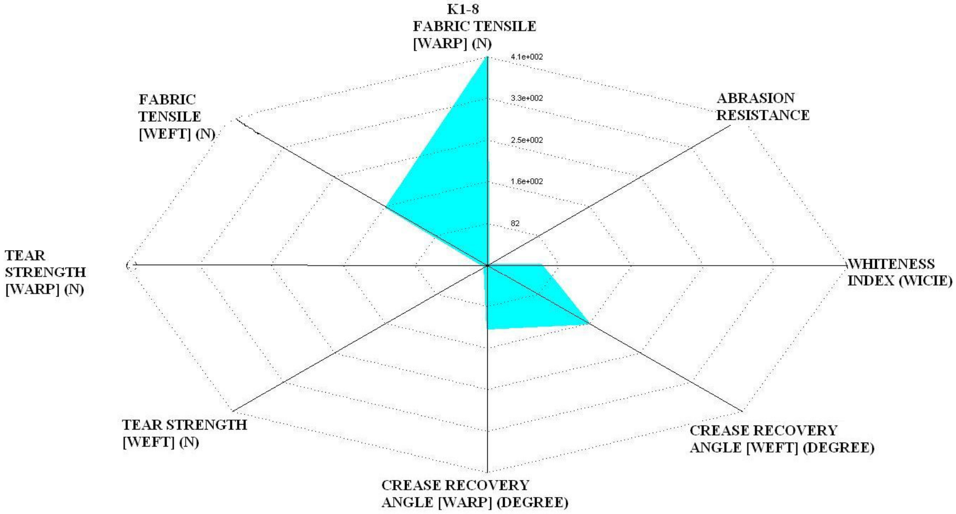


Figure F.8 Multiaxial graph of K1-8 in first group of samples

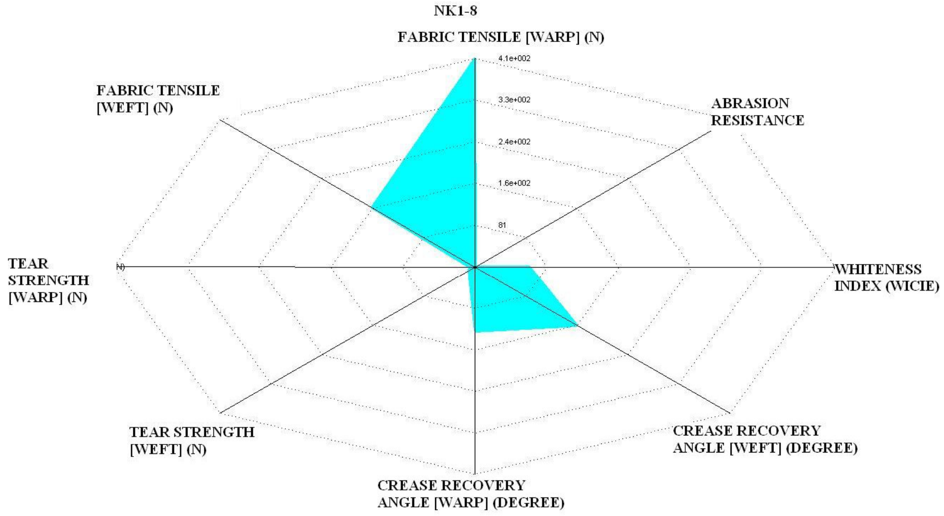


Figure F.9 Multiaxial graph of NK1-8 in first group of samples

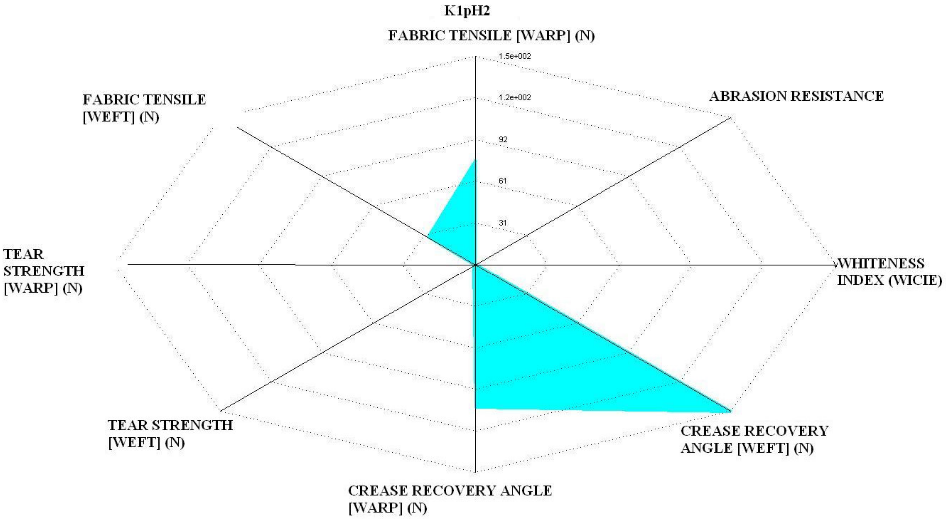


Figure F.10 Multiaxial graph of K1 pH2 in first group of samples

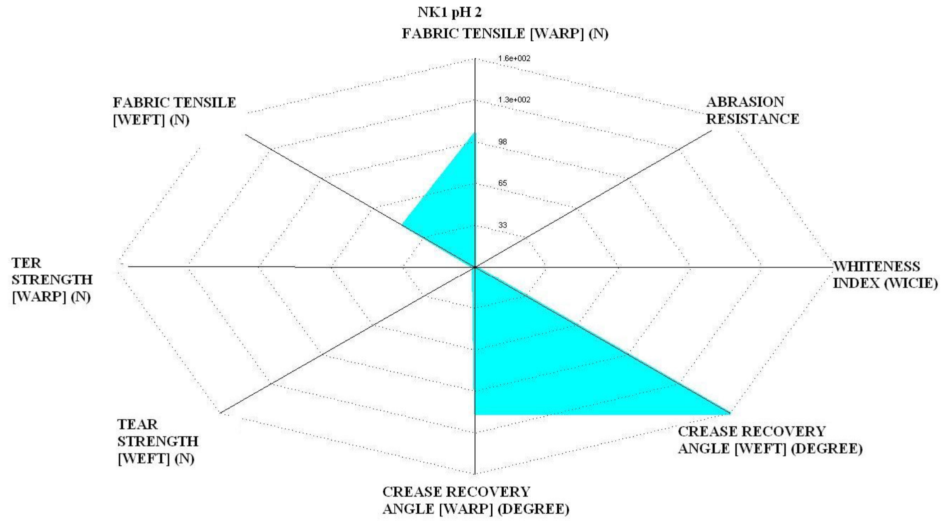


Figure F.11 Multiaxial graph of NK1 pH2 in first group of samples

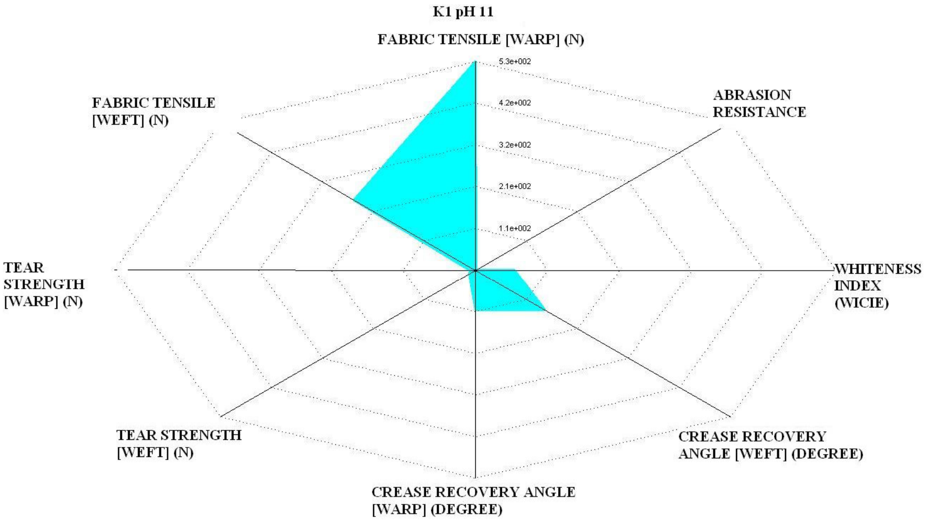


Figure F.12 Multiaxial graph of K1 pH11 in first group of samples

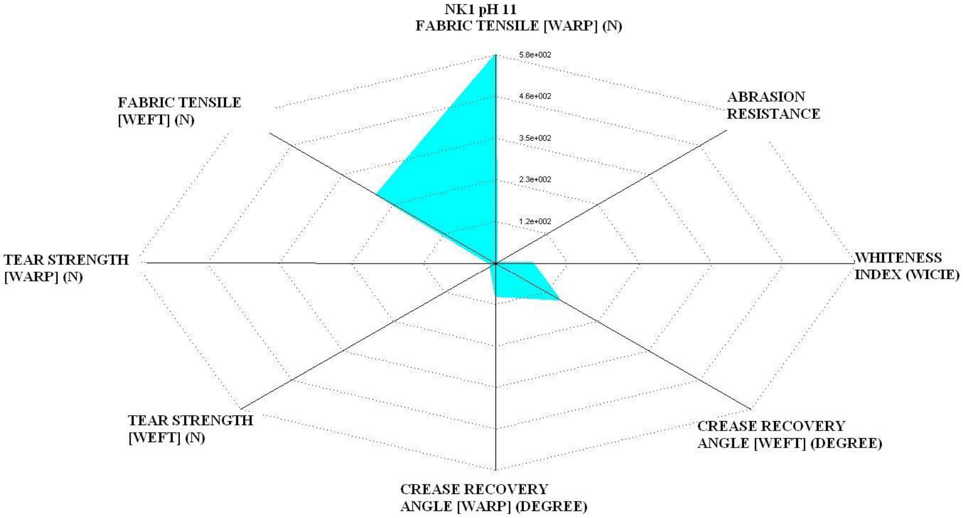


Figure F.13 Multiaxial graph of NK1 pH11 in first group of samples

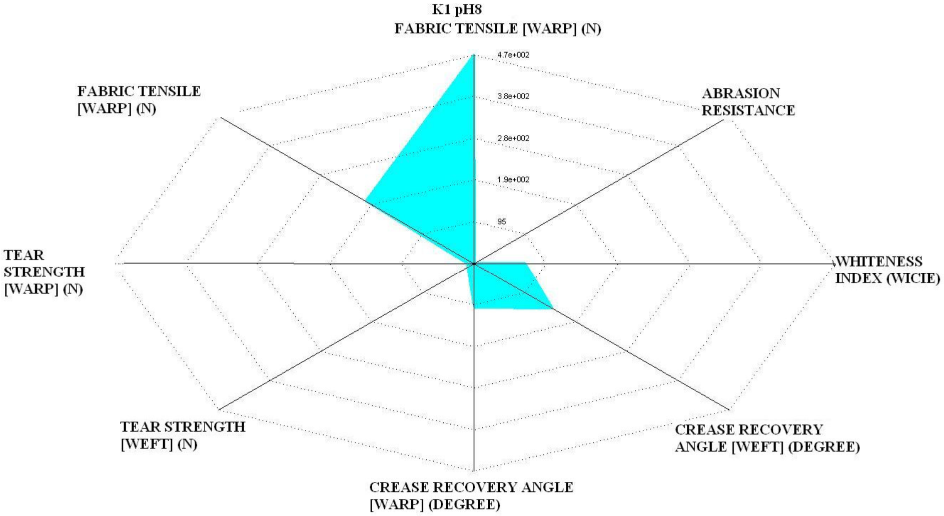


Figure F.14 Multiaxial graph of K1 pH8 in first group of samples

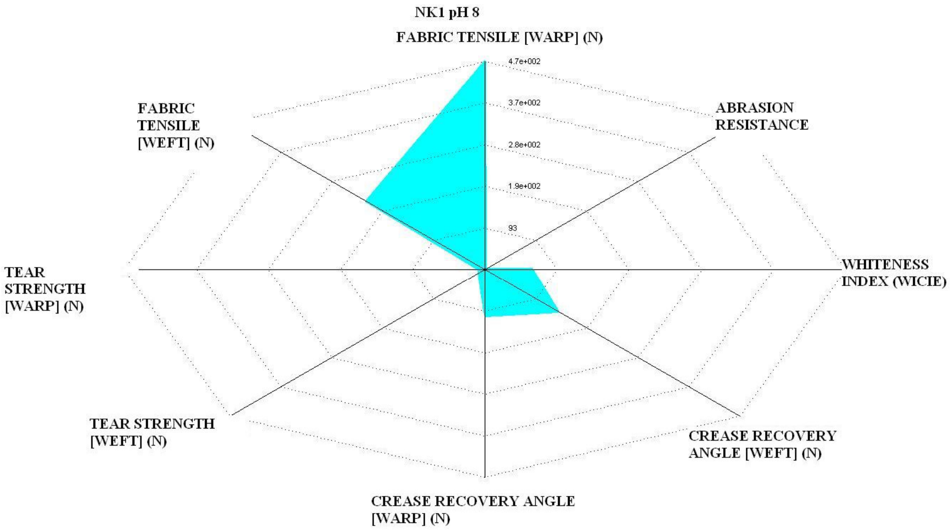


Figure F.15 Multiaxial graph of NK1 pH8 in first group of samples

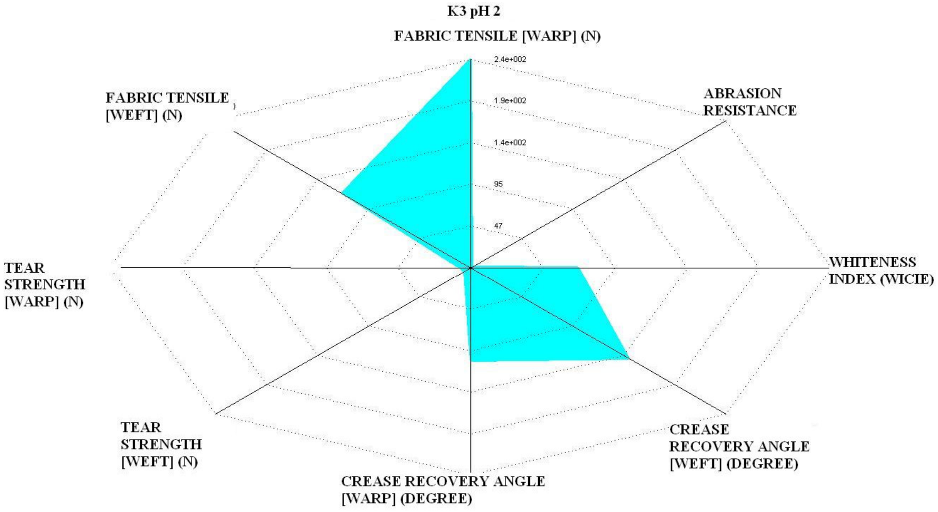


Figure F.16 Multiaxial graph of K3 pH2 in first group of samples

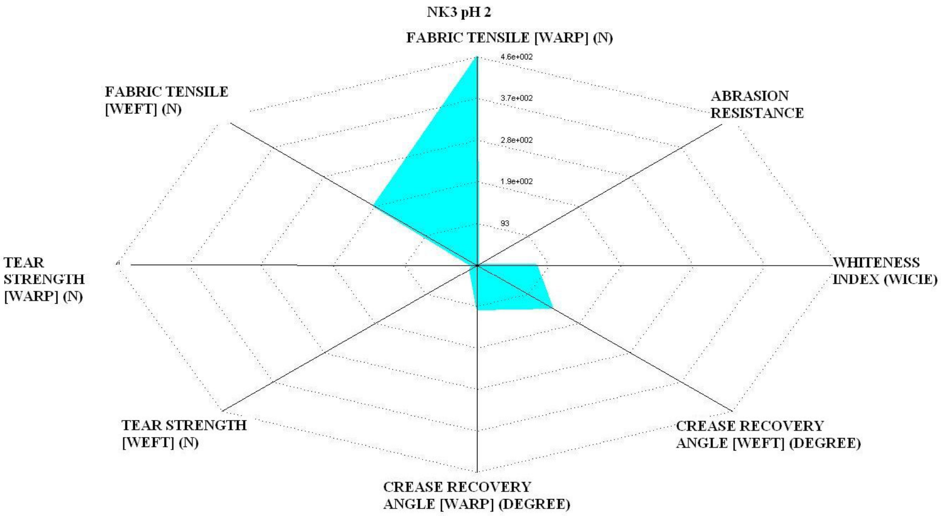


Figure F.17 Multiaxial graph of NK3 pH2 in first group of samples

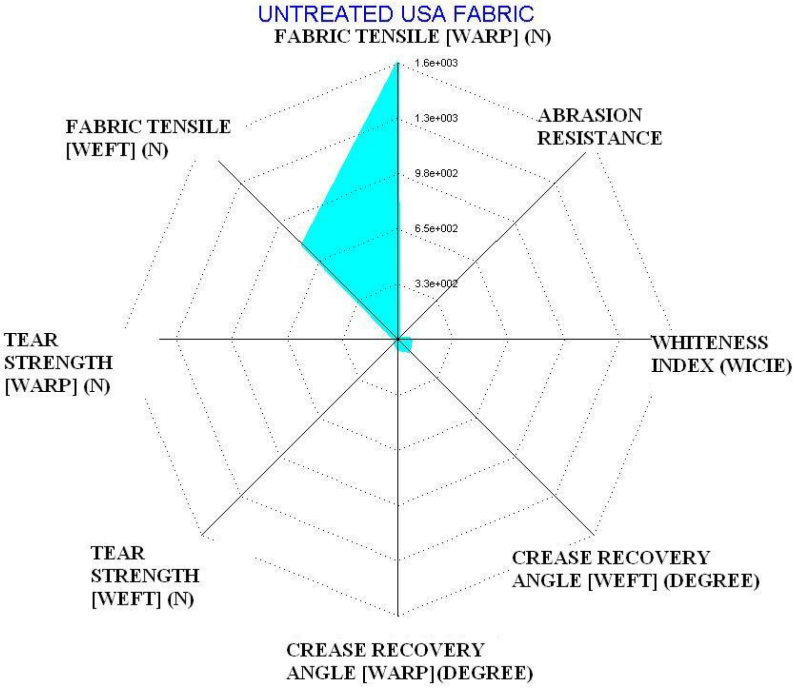


Figure F.18 Multiaxial graph of untreated sample in second group of samples

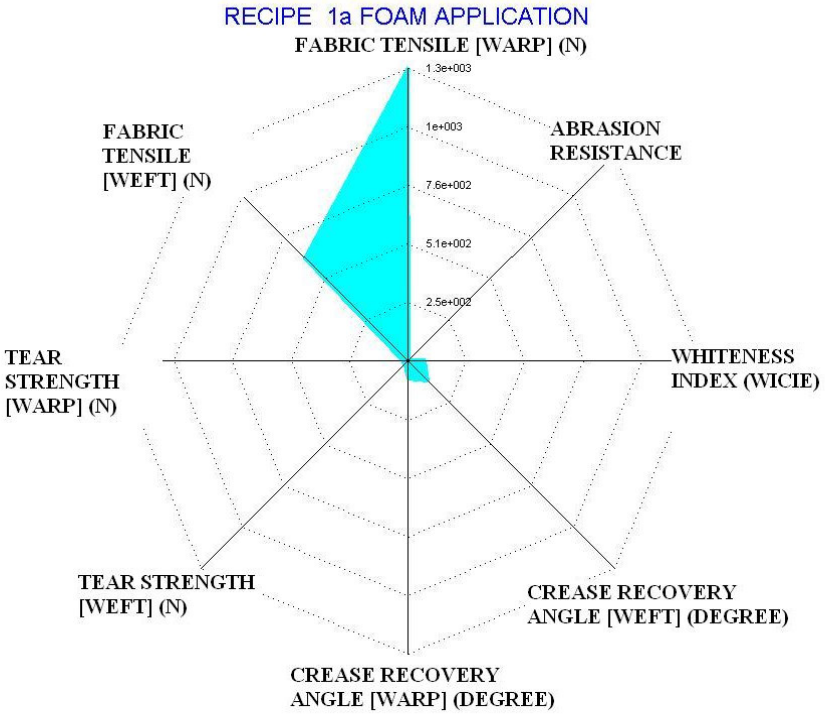


Figure F.19 Multiaxial graph of Recipe 1a foam in second group of samples

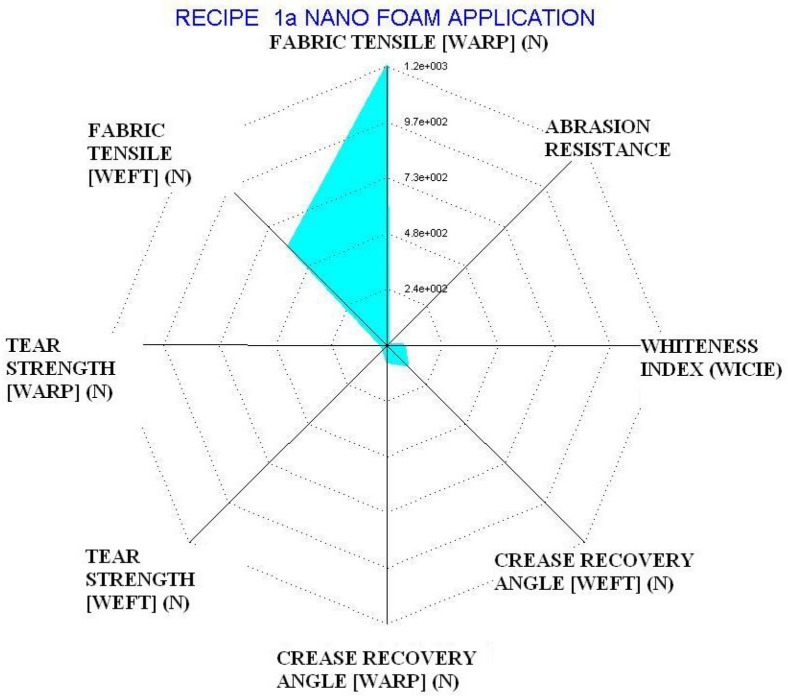


Figure F.20 Multiaxial graph of Recipe 1a nano foam in second group of samples

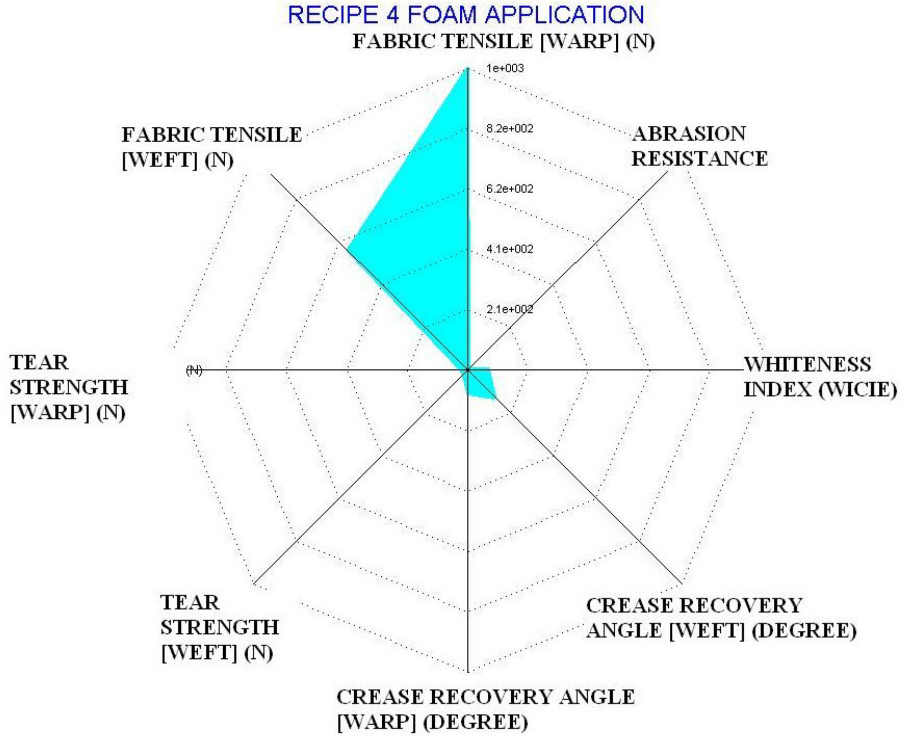


Figure F.21 Multiaxial graph of Recipe 4 foam in second group of samples

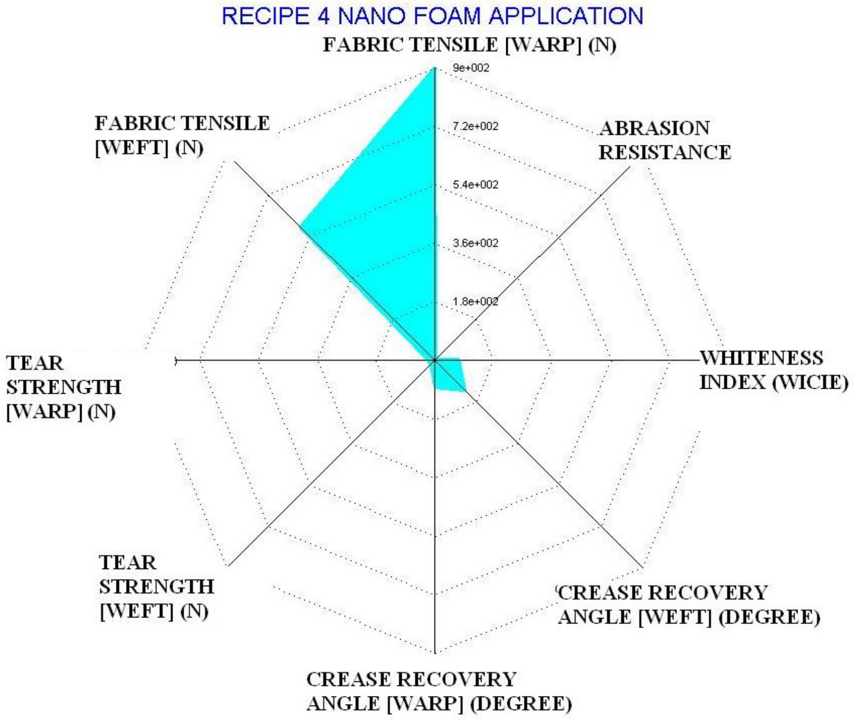


Figure F.22 Multiaxial graph of Recipe 4 nano foam in second group of samples

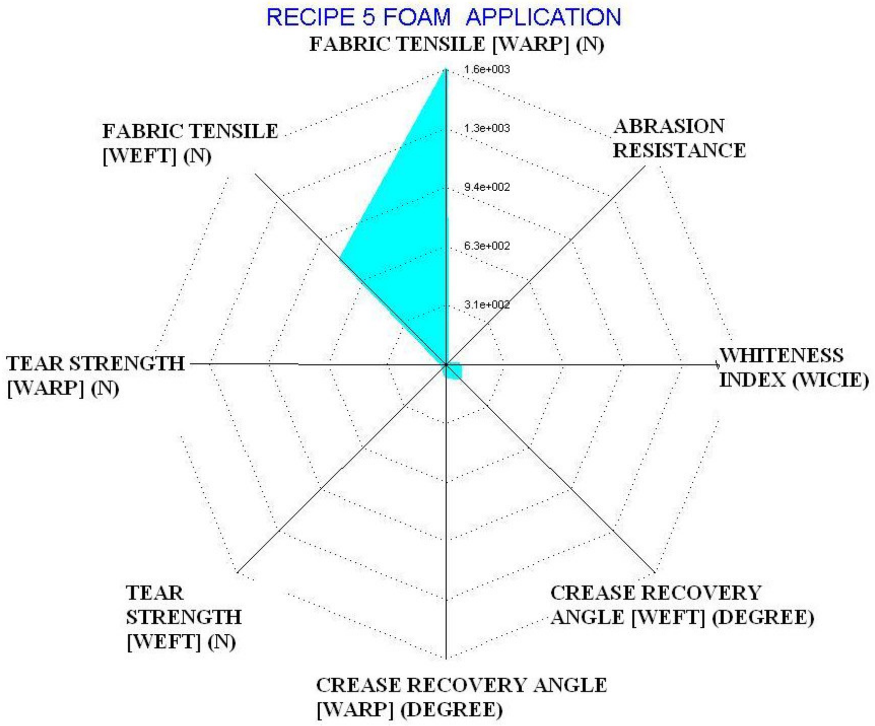


Figure F.23 Multiaxial graph of Recipe 5 foam in second group of samples

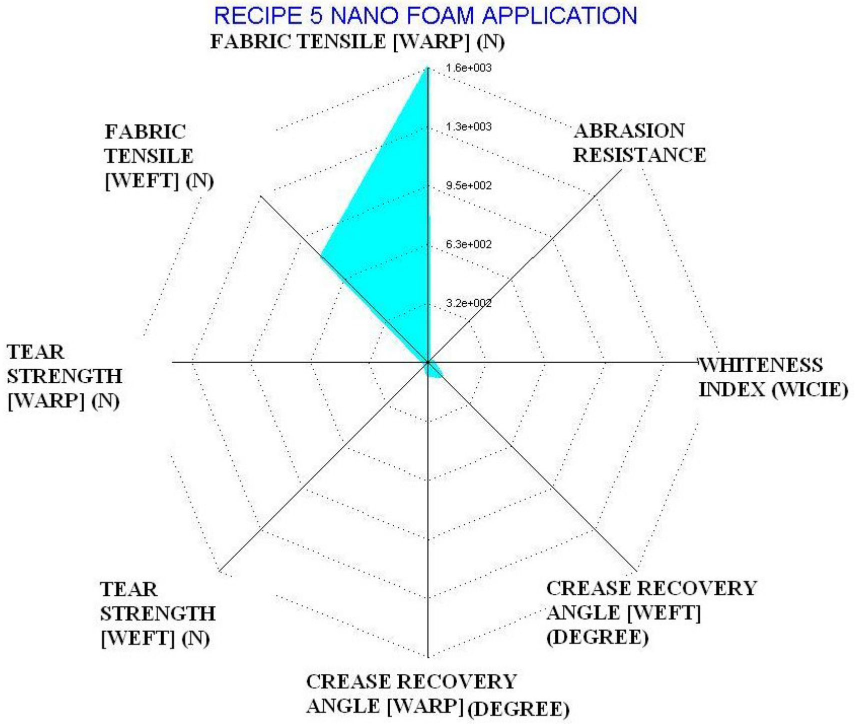


Figure F.24 Multiaxial graph of Recipe 5 nano foam in second group of samples

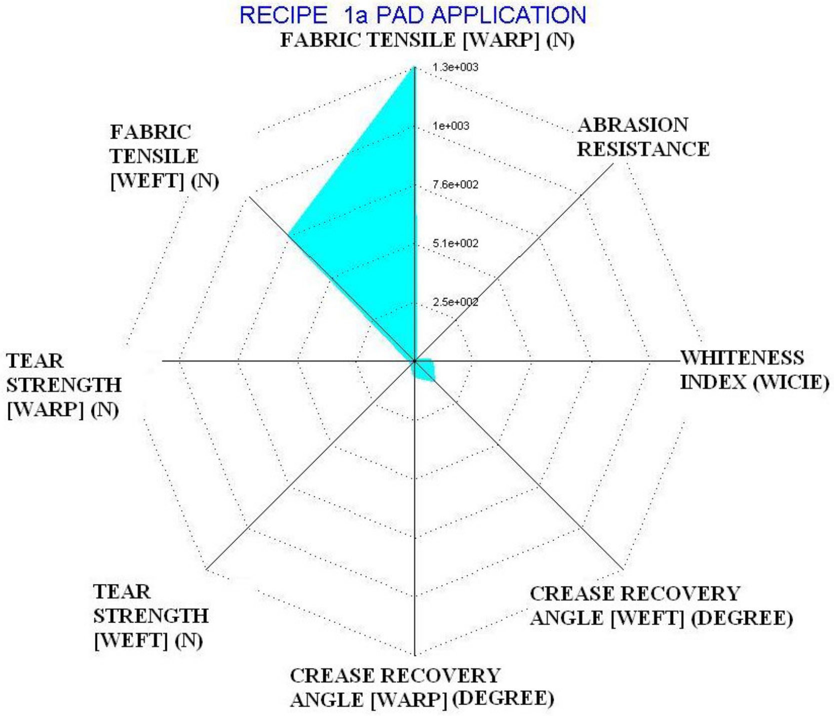


Figure F.25 Multiaxial graph of Recipe 1a pad in second group of samples

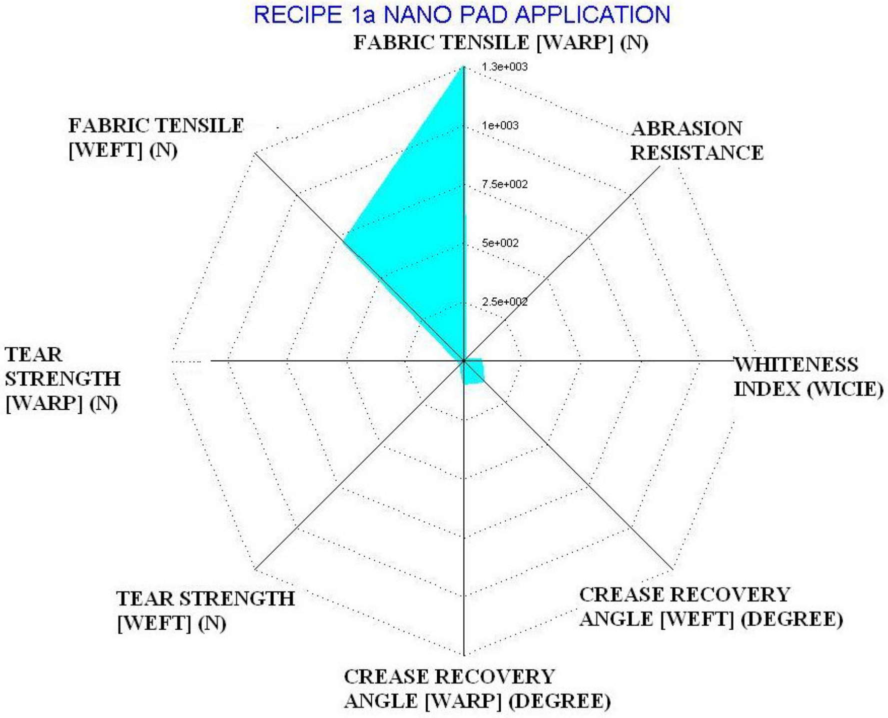


Figure F.26 Multiaxial graph of Recipe 1a nano pad in second group of samples

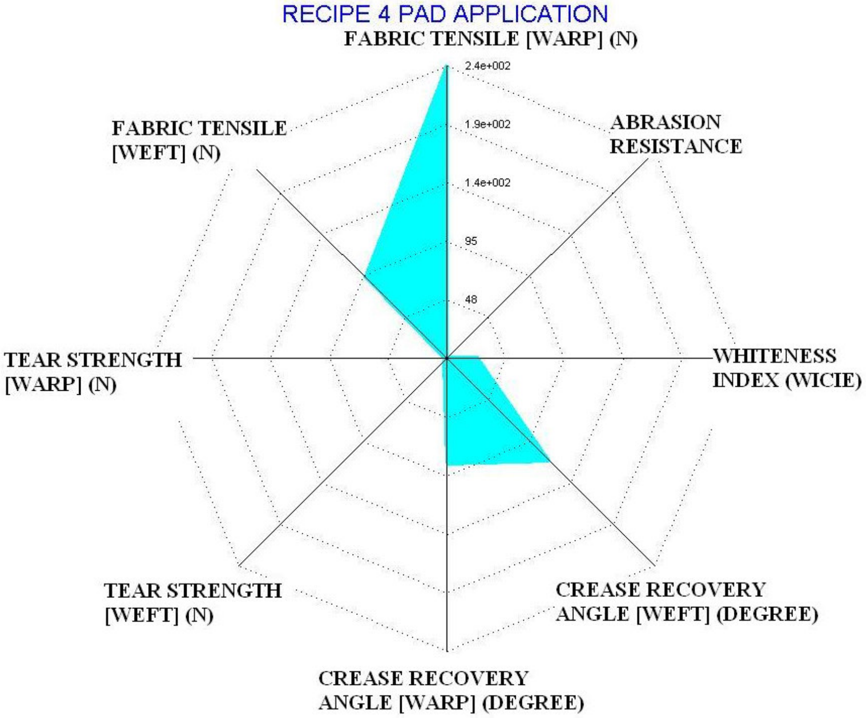


Figure F.27 Multiaxial graph of Recipe 4 pad in second group of samples

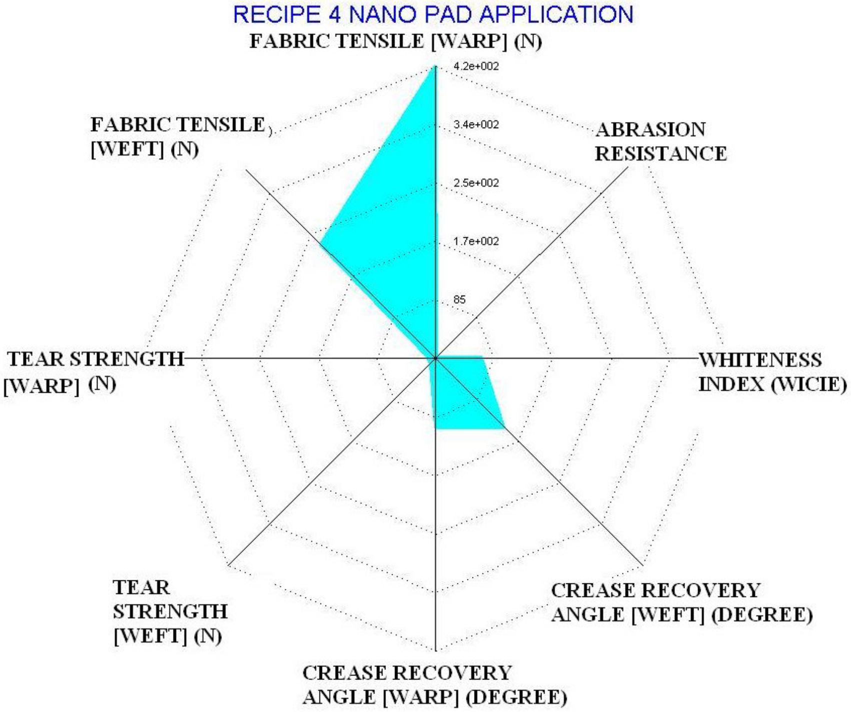


Figure F.28 Multiaxial graph of Recipe 4 nano pad in second group of samples

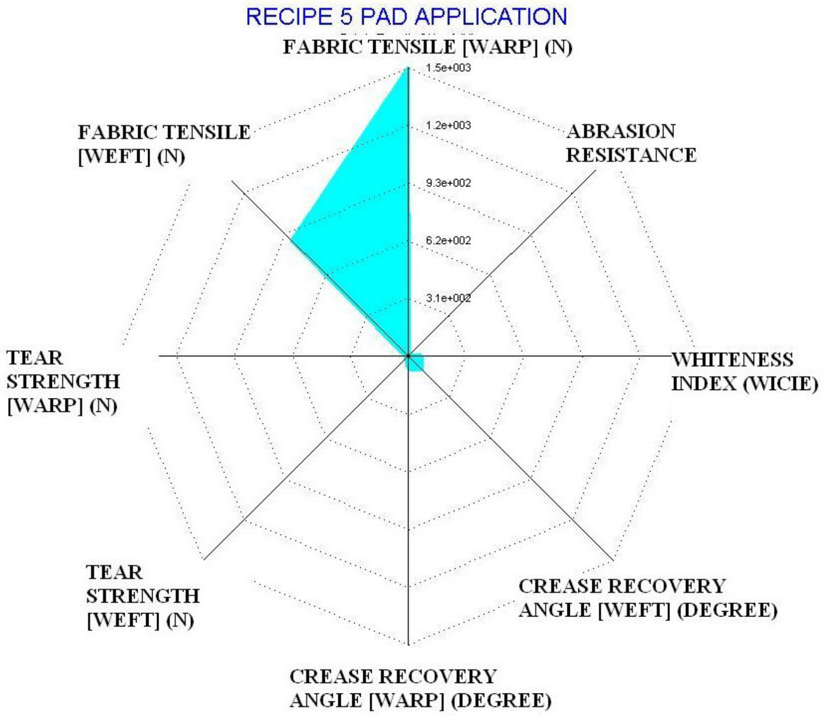


Figure F.29 Multiaxial graph of Recipe 5 pad in second group of samples

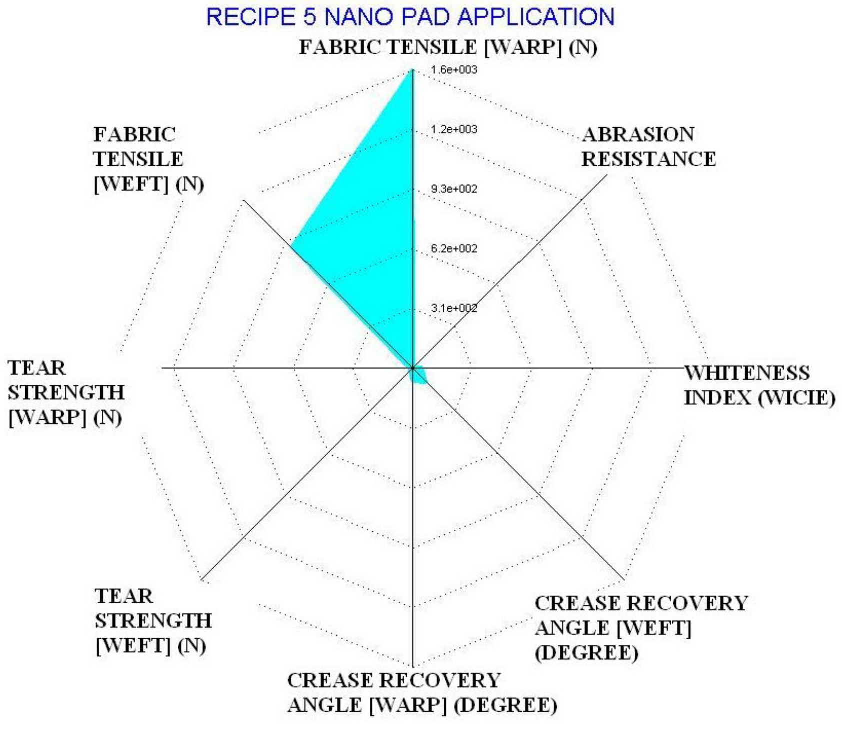


Figure F.30 Multiaxial graph of Recipe 5 nano pad in second group of samples

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