ABSTRACT

MOORE, EMILY ALEXANDRA. The Influence of Staple Fiber Preparatory Equipment on Web Quality. (Under the direction of Dr. William Oxenham.)

The purpose of this study is to determine the impact of pre-carding processes on the quality of the final web. This involves the assessment of fiber properties at various stages of processing as well as the quality of output from each operation. The latter places emphasis on the uniformity of the nonwoven fabrics produced. The study includes various fiber types as well as machine combinations and processing parameters.

Several fiber types were considered and ultimately two different fiber types were used in the experiment, PET and Visil. The machine combinations included the use of a bale opener, mixer, fine opener, scanfeed, card, crosslapper, preneedler and needleloom, all located in NCRC's Nonwovens Staple Laboratory. Fiber and web samples were collected after each machine in each processing trial and assessed by several testing methods. Fiber property testing was performed with the Favimat and Peyer FL101/AL101 instruments. Web uniformity was assessed using a computer image analysis program in addition to the conventional basis weight uniformity method. An emphasis was placed on the image analysis program and further developing its capabilities.

Data collected from the tests was statistically analyzed to reveal the influence of the machine combinations and processing parameters. Where possible the influence of fiber type was also assessed. ANOVA tests were used to compare the data sets, in order to statistically verify any similarities or differences observed. When significant differences were found Fisher's Least Significant Difference (LSD) was used to pinpoint particular influences. Conclusions are made and future work suggested.

THE INFLUENCE OF STAPLE FIBER PREPARATORY EQUIPMENT ON WEB QUALITY

by

EMILY ALEXANDRA MOORE

A thesis submitted to the Graduate Faculty of

North Carolina State University

In partial fulfillment of the

Requirements for the degree of

Master of Science

TEXTILES

Raleigh, North Carolina

2007

Approved by:

Dr. Eunkyoung Shim

Dr. Donald Shiffler

Dr. William Oxenham
Chair of Advisory Committee

BIOGRAPHY

The author, Emily Alexandra Moore, was born on February 14, 1983 in High Point, North Carolina. She graduated from Newton-Conover High School in 2001 and went on to receive her Bachelor of Arts degree in American History and Political Science from the University of North Carolina at Chapel Hill in 2004. In 2005, she joined the Nonwovens Cooperative Research Center (NCRC) at the College of Textiles at North Carolina State University as a research assistant in pursuit of a master's degree in Textile Management and Technology.

ACKNOWLEDGMENTS

I would like to express sincere gratitude to my advisor, Dr. William Oxenham, for all his guidance and direction throughout my research project. His support throughout my time here at NCSU was key to my success as a student and a researcher. I would like to thank Dr. Behnam Pourdeyhimi for his support and encouragement from start to finish as well. Appreciation is also extended to Dr. Eunkyoung Shim and Dr. Donald Shiffler for serving on my advisory committee.

The research would not have been possible without the financial assistance provided by the Nonwovens Cooperative Research Center. I would like to thank all of the NCRC staff, students and member companies for their assistance throughout this project. I would especially like to thank Rob Byron and John Fry for their help with the processing trials, Amy Minton, Jan Pegram and Teresa White for their help with fiber testing and Bruce Anderson for all his help with the image analysis programming.

Finally, I would like to express a special thank you to my family for their constant encouragement and support throughout my academic career and to my friends for their moral support as well.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

There have been significant increases in carding speeds and this has been made possible not only through improvements in the carding machines but also by the improvements in processing that takes place between the bale and feed to the card. Because of this, fibers that have been optimally opened, blended, and if necessary cleaned, can usually be carded at higher speeds and render much better carded web quality. There have also been major improvements in the technology used to feed cards and this can also play a decisive role in web quality.

The purpose of this study is to determine the impact of pre-carding processes on the quality of the final web. This will involve an assessment of the fiber properties at various stages of processing and the quality of output from each machine. The research will utilize the newly installed equipment in the nonwovens staple laboratory, and will focus on the effect of preparation on the quality of feed to the card and the resulting fabric produced. In particular the influence of opening on web uniformity and fiber properties will be determined and whether the trends observed are fiber specific. An emphasis will be placed on the mass uniformity in machine and cross-machine directions. Additionally, the possibility of using non-carded webs as a feed to the needlepunch machine will be explored. The study will include different fiber types as well as machine combinations and processing parameters.

The long-term benefits of this research will be to improve the ultimate quality of carded webs with the added potential that optimum preparation may enable high card productivity. A further possible outcome from the research would be the possibility of eliminating the necessity of the carding machine, but this would obviously be restricted to certain end products.

A number of preliminary trial runs were conducted in the Nonwovens Staple Fiber Processing Laboratory. From these a final experimental trial was planned. The fibers used were PET and Visil fibers. Traditional carded/crosslapped needlepunch fabrics were produced in this trial as well as fabrics using only preparatory machines and a needleloom, completely bypassing the card and crosslapper. Several testing methods were used to assess fiber and web properties in order to analyze the effects of each processing machine.

The proceeding chapter, Chapter 2, explains the four main phases of dry-laid nonwoven manufacturing with an emphasis on the fiber preparation and processing machines involved. It also highlights a few of the machines currently available to nonwoven manufacturers. Chapter 3 details the experimental plan to fulfill the research objectives described above. In Chapter 4, the results of the experimental work are presented and Chapter 5 concludes with findings and recommendations for future work.

2. LITERATURE REVIEW

2.1. Manufacturing Process

There are four main phases of dry-laid nonwoven manufacturing: fiber selection, fiber preparation, web formation and bonding. The first two steps, fiber selection and fiber preparation, focus on choosing fibers based on the processing and product requirements and properly preparing them to be fed to a card. The last two phases for producing a dry-laid nonwoven are the web formation and layering and the bonding and stabilization of the web. The web formation and layering stage includes the carding process and crosslapping, if desired. Dry-laid webs can be stabilized or bonded by a variety of different methods.

2.1.1. Fiber Selection

The first phase of dry-laid nonwoven production, fiber selection, is one of great importance. Staple fibers chosen must satisfy processability and product requirements at an acceptable cost. For these reasons the most frequently used fibers in dry-laid production are polyesters, polypropylene, viscose rayon and bleached cotton.[13] Product requirements and cost are dependent on the particular application of the nonwoven being made, so for the most part these cannot be generalized. The processability of fibers however can be. The five most important characteristics of a fiber that influence their processability are fiber fineness, fiber length, crimp, tensile properties, and fiber finish. Other characteristics can be important as well. Some additional fiber properties that can affect processability include fiber shape, fusing and melting temperatures, luster, and moisture content.[13]

2.1.1.1. Fiber Fineness

Fiber fineness can be measured by several ways including relative size, diameter, and linear density. The direct measurement of fiber diameter provides an accurate way for comparing fineness, but fibers' cross-section needs to be perfectly circular for this. Since few fibers actually are circular, indirect methods are used to determine the fiber fineness.[14] Linear density is the most common method used for comparing fiber fineness. Most frequently linear density is expressed in either denier or decitex. A denier is the weight in grams of 9000 meters of a fiber and decitex is the weight in grams of 10,000 meters of fiber. The fineness of a fiber has a great influence on its processability. Lower denier fibers typically result in softer, more uniform nonwoven fabrics, but this is at the expense of their production rate. Since these fibers are fine, they cannot be processed at high rates without a great deal of fiber breakage and nep formation. Larger denier fibers can be processed at higher rates with less fiber breakage, but produce less uniform webs.[13] For needlepunched nonwovens the typical denier range is from 1 to 15 denier.[35]

2.1.1.2. Fiber Length

Fiber length is another important characteristic that affects a fiber's processability. For a fiber to be able to be processed into a nonwoven fabric, it must be long enough to allow processing and slender enough to be flexible. Therefore, the length to diameter ratio of a fiber is very important. The fiber length also affects the fabric tensile strength. As the length of the fibers increase, so does the fabric strength. Finding an optimal fiber length is important because short fibers tend to decrease the uniformity of webs since they are harder to evenly distribute, but fibers that are too long make opening and separating the fibers more difficult, which also decreases uniformity.[35] Cut lengths of fibers used for dry-laid nonwovens typically vary from one to four inches.[13]

2.1.1.3. Crimp

The crimp of a fiber is the waviness along the length of the fiber. It is expressed in crimps per linear inch or in crimp percentage. Crimp is already present in natural fibers, but it must be added to manmade fibers. The crimp in man-made fibers can be set, partially set or unset. Fabric characteristics such as fullness, bulk, soft handle and high insulating capabilities can be achieved by using fibers with set crimp. Partially set and unset crimp fibers are most often used for short-staple processing to improve the processability of the fibers. They enable easier opening, an improvement in cardability and a reduction in drafting problems. Partially set and unset crimped fibers also help to create a better web because the fibers are able to interlock with each other.[20]

The crimp of a fiber is crucial to its processability, especially for the preparatory processes. Crimp provides the gripping of the fiber to the wired cloths of the equipment. A fiber with very high crimp is difficult to process due to the high resistance to mechanical opening. High crimp also creates drafting problems because the drafting force required increases with increasing crimp.[20] Low crimp fibers are also hard to process because there is insufficient gripping to the wired cloths. Crimp also provides the cohesive strength of the fibrous web before it is bonded, which is important when transporting the fiber between processes.[3] If the crimp is too low the web will break from the lack of cohesion. In addition to this, the crimp affects the loft and tensile properties of the finished fabric. Fibers used for dry-laid nonwovens typically have medium to high crimp.[35]

2.1.1.4. Tensile Properties

A fiber's tensile properties are important because it must possess enough strength to with-stand processing by the machinery and also provide the desired durability for the nonwoven fabric produced.[38] It also must possess some elasticity so that it does not break during processing. If the fiber is too elastic it will cause processing problems as well. The tensile strength of a fiber is determined by tension tests that apply a tension load to a fiber until the fiber breaks. The load when the fiber breaks is the breaking load. This is in turn used to express the tensile strength of the fiber by reporting the force per unit of linear density. Therefore, the tenacity of a fiber is expressed in grams per denier.[14] The tenacity is not only important for determining the physical strength properties of the nonwoven fabric being produced, but it is also important for withstanding fiber breaking tensions during processing. Most staple fibers used for dry-laid nonwovens have tenacities from 3 to 8 g/den.[13]

2.1.1.5. Fiber Finish

The finish of the fiber is also important to its processability. Fiber finishes are generally a mixture of lubricants and antistatic agents added during the fiber spinning and drawing process.[37] The type and percent of finish are important during the dry-laid manufacturing process. The transfer and opening of fibers depends on the proper friction between the wire clothing and fibers as well as the friction between the fibers themselves, this is all influenced by the finishes present on the fibers being used.[13]

2.1.2. Fiber Preparation

Fiber preparation is the second of four phases involved in producing dry-laid nonwovens. The main objective of the preparatory equipment is to mechanically separate and open fiber clumps, reducing the size of fiber tufts from the bale to the chute feed. Since staple fibers are shipped to the manufacturer in highly compacted bales containing 400-500 pounds of fiber, these bales must be opened and the fiber separated. Intense pressure and long periods of bale storage also contribute to fiber compacting and the need for sufficient opening.[4] This is done through mechanical and pneumatic processes of handling from the bale to the point where the fiber is introduced into the web-forming machine.[6] During fiber preparation often times different bales of fibers are blended. Sometimes the same fiber type is used, other times different fiber types are blended together. Either way, the different bales must be mixed and the goal is to produce a homogeneous mixture. A uniformly blended fiber mix is a prerequisite for the production of a uniform, nep-free fiber web to be produced into a quality nonwoven. The ultimate goal of fiber preparation for dry-laid nonwoven production is to produce this uniformly blended fiberfeed.[23]

In order to attain this uniform feed, several preparatory steps are taken. Progressive opening of tufts is necessary in order to minimize damage to fibers, so different types of machines with different intensities of processing are required. Because of this, the fiber clumps continually become smaller as they pass from machine to machine. Progressive opening also helps to minimize the creation of fiber entanglements called neps and to make progressive cleaning and mixing of the fiber tufts possible.[23] Each machine is designed to give optimum performance at its position in the line and at any other position it would give less than optimum performance.[19]

There are no universal preparatory machines or lines since the number and type of fiber preparation differs depending on the intensity of preparation and opening required. The actual selection of opening and blending equipment for dry-laid nonwovens is based on the nature of the fibers and the characteristics discussed earlier as well as the dirt content, material throughput, and the number of different origins of the material in the blend.[19] It is also dependent on the way in which the card is fed. With this said, there are some typical preparatory machines that most lines include: a bale-opening machine, a blending machine, a fine opener, and some type of card feeding equipment.[20]

2.1.2.1. Bale Opening

The first step of fiber preparation is bale opening. As mentioned before, the fiber comes tightly compacted in bales of 400-500 pounds and must be opened and the fiber separated. Bale opening rolls have spikes that tease and tear away at the fibers taken from the bales. With this action, the machine opens the bales into tufts and removes most of the impurities while blending the fiber together. A picture of the bale opener found in NCRC's Nonwoven Staple Laboratory can be found in Figure 1.

Figure 1: Trützschler Bale Opener in the Nonwovens Staple Laboratory

Bale opening can be conducted by a set of hopper feeder machines or by a top feeder. Hopper feeders have stock supply compartments that can be filled manually or by automated machines that duplicate the human bale feeding process. A set of parallel hopper feeders can significantly contribute to fiber mixing. Top feeder machines are the more popular machine used. A top feeder works much like a vacuum. It travels back and forth over a laydown of bales picking up layers of fiber from each bale with opening devices. They only contribute minimal fiber mixing, but prepare the fiber tufts for mixing downstream.[23] With modern equipment, up to 80 bales can be lined up on the floor and opened by a programmable top feeder.[39] With both of these machines, the initial bale feeding takes place in addition to the initial tuft opening.

With fiber preparation, it is very important to maintain uniformity and an even distribution of fibers throughout the system.[15] This can be achieved by controlling the number of bales of each fiber type and the order of fiber delivery in the bale lay-down.[14] The fiber amount can be controlled by either weight or by feeding on a volumetric basis. Since the fiber is coming from such highly compacted bales, further processing is needed before going into the card.[6] The next step in a processing line is typically blending.

2.1.2.2. Blending

Nonwovens are produced in large quantities and thus several bales of fibers are used for each production run. The goal of blending is to optimize the homogeneity of the fiber mixture when combining these bales. Mixing also decreases irregularities in bales of different origin.[39] Because of the significant variability in fiber properties within and between bales, the fiber needs to be thoroughly mixed regardless of whether the bales are all the same type or different types of fiber.[23] One way in which blending equipment does this is by gently opening the tufts of fibers from the interaction of an inclined needle lattice apron and an evener roller equipped with needles.[6] The ultimate goal of this process is to create consistency within a production run and hopefully between production runs, so that quality of the product can be uniform over long periods of time. This is more problematic with natural fibers and is usually solved by mixing bales of different fiber types to yield a blend that can be duplicated.

The fibers from different bales, and different types of fibers, are fed in a series so that they are mixed and blended together to produce a statistically averaging effect. Often times further blending is achieved by re-circulating the fiber mix back through the mixer or by transferring the fiber mix to another mixer. Although blending helps to gain a better fiber mix and also in opening tufts, excessive blending can be damaging to the fibers and can create higher nep counts. There is also the possibility that excessive blending could result in blend separation. This can occur when fibers with different properties such as fineness, length, and friction actually self sort, resulting in, for example, tufts of all fine fibers and tufts of all coarse fibers. Therefore, an optimum amount of mixing, depending on fiber selection, must be found.

There are many types of machines that can be used for blending fiber. One type of machine, a hopper feeder, deposits fiber tufts on to a conveyor on top of fiber from other hoppers so that a sandwiching affect from different bales is created. While the hopper is depositing fiber, stock from multiple bales is rolled and tumbled in the reserve section, contributing to the mixing affect.[23]

Another popular machine for mixing tufts is a cell mixer. Cell mixers mix fiber by depositing tufts from a prior process, sequentially or randomly, into a set of parallel vertical chambers. Stock is simultaneously removed at the bottom of the chambers, so that the output has tufts from each chamber. These machines are also called time-delay blenders or blender/reserves.[23] The images in Figure 2 show these two types of continuous mixers offered by Trützschler.

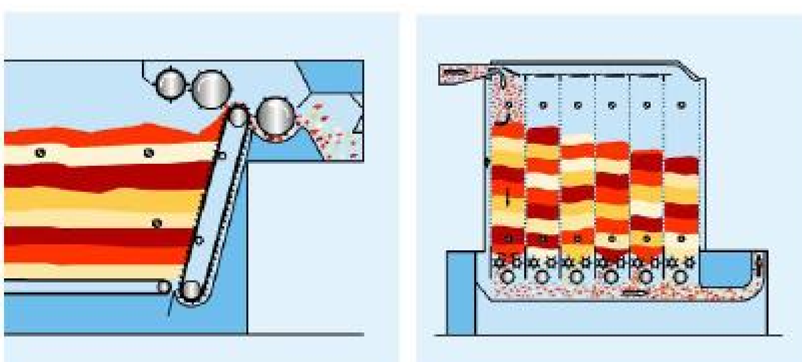
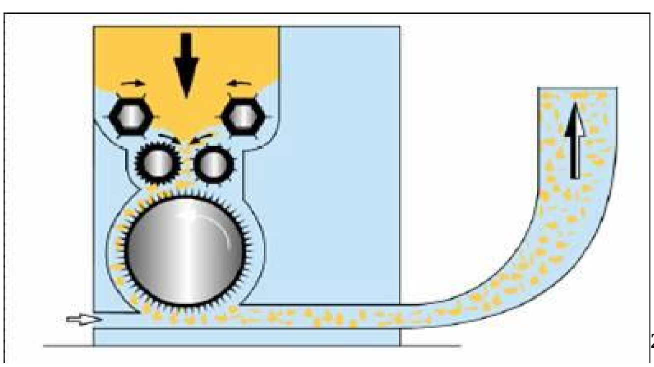


Figure 2: Trützschler Continuous Mixers

If different types of fibers are being blended together, the fiber types can be weighed out for the proportion desired and then deposited into mixing machines. There are three main machine systems in use for weight-based blending for different fiber types. These are weigh-pan hopper feeders, belt-weighing machines and chamber type, pressure sensor equipped machines.[23] Weigh-pan hopper feeders are generally good for controlling overall blend composition but do not produce intimate mixing by themselves.

2.1.2.3. Fine Opening

After initial bale feeding and mixing, fiber tufts must be further opened and cotton fibers must be cleaned. A fine opening machine typically performs this process. Fine opening provides intensive opening of the fiber mix to fully open the fibrous material. For one hundred percent synthetic fibers often only one additional opening process is sufficient, so the fine opener can also be used as the distribution point for feeding the card chutes.[23] Using the principle of carding points, the wire clothing on the surface of the opening roll tears apart the remaining tufts and clumps of fibers.[13] This concept can be seen in Figure 3.



2

Figure 3: Fine Opener

Fiber opening is one step of the pre-carding processes that is crucial to the formation of a successful nonwoven web. Fiber opening is important for nep removal and improved uniformity. Adequate opening of fibers can lead to improvements in carding performance and also productivity since successful carding and web formation is dependent on a uniform feed to the card. But there must be an optimum amount of opening because excessive opening of fibers can increase fiber breakage and nep content and because of possible excessive bulk, also limit the amount of fiber fed to the card, which can result in lower productivity.

2.1.2.4. Card Feeding

Once the fibers are adequately opened and mixed, for the production of dry-laid nonwovens, they must be fed to the card. If the fine opener is not used to feed the card, then a tuft feeder, also referred to as a feed chute, typically does this. The feeder in front of the card is a very crucial machine for the production of a uniform web. The purpose of the feed chute is to form a continuous and even mat of small fiber tufts to be fed into the card.[22]

The ultimate goal is to form a mat of small fiber tufts that has a continuously even amount of fiber in both machine and cross machine direction, is consistently well opened and is delivered to the card feed roll in a uniform manner.[23] An even feed to the card helps to ensure an even web coming out of the card. It is often said, ‘good input equals good output.’ In recent years, the manner in which the card is fed has gained a great deal of importance especially in the case of products where the uniformity of appearance and performance is a determining factor of its quality.

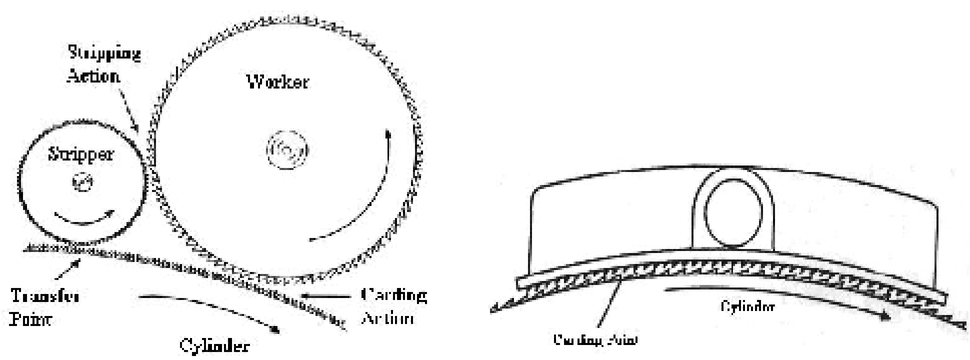
Many of the early feed chutes were basically simple box-like compartments with delivery rolls at the bottom to discharge the stock onto the card feed table when the feed roll of the card was operating. For the most part, these chutes had very poor and erratic product weight control and any slight change in ambient conditions and pressure caused the longitudinal weight of the stock to vary considerably.[23] Machine manufacturers have developed more sophisticated designs to improve the feeding systems.

One important change that machine manufacturers have implemented is the use of double compartments in the chute to separate the mat-forming chamber in the lower part from the pressure changes created by the transport duct above. A fan in the chute keeps a consistent air pressure on the fibrous stock in the lower mat-forming compartment. A pressure sensor in the lower chamber activates the feed roll in the upper chamber, so that when the feed roll is not turning, no stock is delivered to the mat-forming compartment.[23] As long as the stock is well opened as it enters the transport duct, this more innovative chute design will deliver a very satisfactory mat to the card.

2.1.3. Web Formation

When producing dry laid nonwovens a carding machine is typically used for web formation. The main objective of a card is to separate small tufts into individual fibers, to begin the process of "parallelization" and to deliver the fibers in the form of a web.[6] The fibers are fed by a chute or hopper and condensed in the form of a lap or batting. This is opened into small tufts by a licker-in, which feeds the fibers to the cylinder of the card.[6] When the fibers are thoroughly separated prior to the cylinder, more effective carding takes place between the cylinder and flats. This more effective carding includes fiber alignment, mass uniformity, cleaning, and nep removal which are all enhanced by optimizing the preparatory processes.[23]

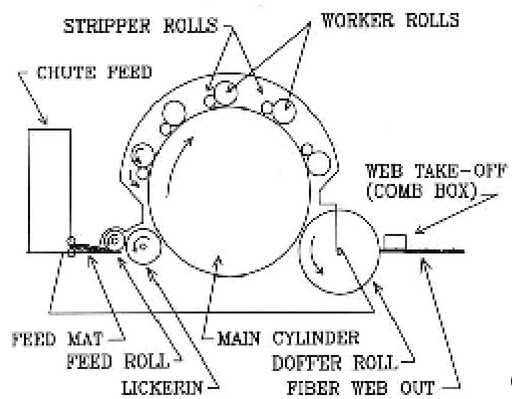
The large rotating cylinder in the card is “covered with wire pins or teeth and a series of flats, which have a rough granular surface somewhat similar to rough sandpaper or, most commonly, wire card clothing. The flats form an endless belt that rotates above the card cylinder. The cylinder and the flats rotate in the same direction but at different speeds, to tease the fibers into a thin, filmy web.”[14] The carding action described above is visually depicted in the images found in Figure 4.



[6]

Figure 4: Carding Action by Roller-Top Card and Flat-Top Card

The top may be covered by alternating rollers and stripper rollers in a roller-top card. In the roller-top card the separation occurs between the worker roller and the cylinder. The stripping roller strips the larger tufts and deposits them back on the cylinder. The fibers are aligned in the machine direction and form a coherent web below the surface of the needles of the main cylinder.[6] The basic construction of a roller-top card and its parts, as described above, can be found in Figure 5.



[6]

Figure 5: Basic Construction of a Roller-top Card and its Parts

Some of the main manufacturers of nonwoven carding machines, which are typically roller cards, are Houget Duesberg Bosson (HDB) of France, Hergeth Hollingsworth of Germany, Spinnbau Bremen of Germany, Thibeau of France (part of the NSC Group) and Fonderie Officine Riunite (FOR) of Italy.[30] Nonwoven cards are different from textile mill cards, for spinning yarn, in several ways. First they are shorter than textile mill cards. The fleeces delivered from the doffers are not transformed in band (sliver or roping) like in textile mills. Also the fleece condensing part is excluded. Current industry demands include larger working widths, higher production capacity, better end product quality, and more efficiency and availability influence modern machine designs.[30]

To increase throughput and fabric weights layering can be employed by a crosslapper. The general principle of crosslapping is that "the fiber fleece delivered by the card is laid zigzag ($\alpha 1$ and $\alpha 2$ angles) by the cross-lapper onto a transport belt, situated at 90^o angle to the transport direction of the fleece."[30] Crosslapping improves web uniformity by stacking layers to balance out variations in basis weight. Figure 6 shows a typical crosslapper and the general principle behind the technology.

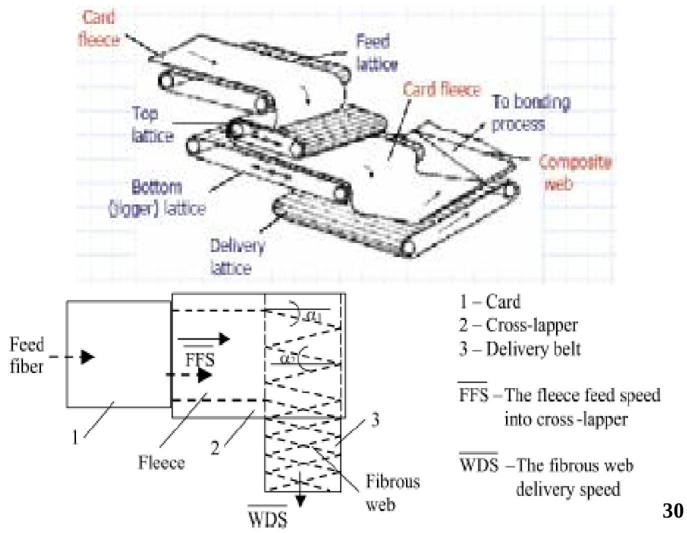


Figure 6: A Typical Crosslapper and the General Principle

Crosslapping also enables different types of fiber mixes to be used in web layers to produce composite fabrics. Main manufacturers of crosslapping machinery are Asselin of France, Autefa and Hergeth Hollingsworth of Germany, and Tatham of England.[30]

2.1.4. Bonding

Carded fiber webs can be bonded in a variety of different ways including thermal bonding, calendaring, thru-air bonding, chemical bonding, foaming, immersion, spraying, hydroentangling and needlepunching. These bonding processes can yield many different benefits.[30] The four bonding methods frequently used for drylaid nonwovens are, thermal bonding, resin bonding, spunlacing and needlepunching. The nonwoven fabrics produced by each of these technologies have different characteristics and can be used in different markets and products. Thermal bonding is a process that uses heat to bond a web structure containing thermoplastic fibers.[6] Resin bonding is a generic term for interlocking fibers by the application of a chemical binder.[5] The combined production of carded thermal and resin bonded nonwovens worldwide totaled 717,000 tonnes during 2004. Spunlacing, also known as hydroentanglement, is a mechanical process that uses high-pressure water jets to interlock fibers together.[7] Spunlaced technology is becoming an increasingly important bonding technology for dry-laid nonwovens. In 1994 spunlaced accounted for 11% of the total carded nonwoven production. By 2004 it had increased to 21% and is forecasted to increase its share to 28% by 2009. Needlepunching is a process used to bond nonwoven webs by mechanically interlocking the fibers with barbed needles. Needlepunched nonwovens have grown worldwide at a rate of almost 6% per year between 1994 and 2004. This technology produced 907,000 tonnes of fabric in 2004.[18] All of this can be seen in Table 1.

Table 1: Worldwide Carded Production by Bonding Technology (tonnes)

Bonding Technology	1994	1999	2004	2009 Forecast
Thermal/Resin	552,000	758,000	717,000	635,000
	46.2%	44.2%	34.8%	23.7%
Spunlacing	126,000	230,000	435,000	761,000
	10.5%	13.4%	21.1%	28.4%
Needlepunched	517,000	728,000	907,000	1,285,000
	43.3%	42.4%	44.1%	47.9%
Total Carded Production	1,195,000	1,716,000	2,059,000	2,681,000 [18]

2.2. Preparatory Equipment

Since the preparatory process is so crucial to producing a quality dry-laid nonwoven much attention has been focused on this particular phase of manufacturing. It is believed that by improving these processes, ultimate web quality can be improved. Manufacturers of staple fiber preparatory equipment are well aware of the important role their machines play in the manufacturing system and continue to advance their capabilities. This can be seen with the recent innovations in card feeding systems. Other recent advances in preparatory equipment have been in microprocessor-based control features and workplace safety features. Some of the advanced safety features include the ability to capture metal debris during pneumatic transport of opened fiberstock and near-instantaneous shutdown of the entire processing system in case a fire starts in the pneumatic transport ducts.[29]

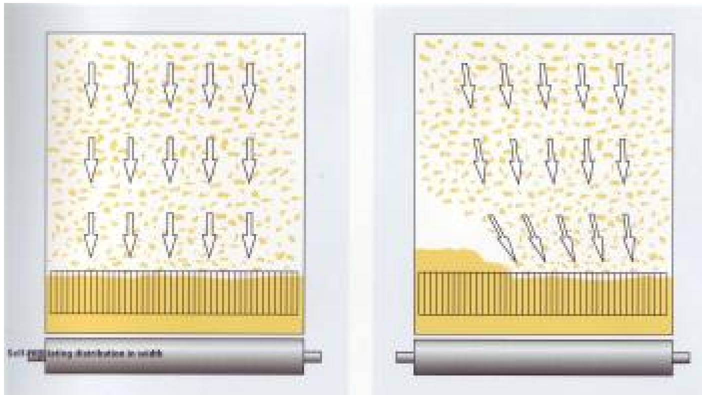
Some of the main manufacturers of staple fiber preparatory equipment are Trutzshler, DOA, Temafa, Ommi SpA, and Pneumatic Conveyors. The machines they produce today are highly automated and offer complete computer control systems for their operation. Unlike traditional textile lines, there is no such thing as a nonwovens line.[29] Most preparatory lines are tailor-made since the equipment selection and amount of preparation is dependent upon the end use of the nonwoven fabric and the budget associated with it. Many of these companies find out from their customers what kind of fiber and applications the machines will be used for and then with the help of Computer Aided Design software they construct the actual preparatory line. The following are examples of preparatory machines and equipment available today with advanced automation and material handling capabilities.

2.2.1. Trutzschler

Trützschler, GmbH & Co. KG is a leading machine manufacturer out of Germany. They produce machinery and systems for spinning mills and the nonwovens industry. Trutzschler is known for setting the standard in the area of bale opening, blending and mixing.[29] Not only does Trutzschler offer a wide range of opening and blending machines they offer innovative control systems for these machines and the only card feeding system on the market that controls web thickness in both machine and cross machine directions.[2]

Trützschler's two types of high-production openers, the Tuftomat and the TO-U, have production rates of 1,5000 kilograms per hour (kg/hr). The Tuftomat machine was designed to process bleached cotton, polyester and polypropylene. The TO-U machine can process staple fibers over 60 millimeters, with three opening rolls to control the degree of opening desired.[29] Their mixers are continuously working mixers instead of mixing chambers, which creates a more homogenous blend and saves space. The system also has a small storage unit built into the opening line to create a more uniform material flow.[29]

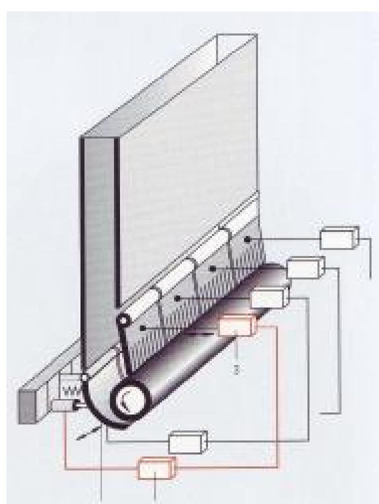
Trützschler also offers a number of options for card feeding: through a bale opener, feed trunks or even with feeding units equipped with opening rolls. The most innovative preparatory machine offered is Trützschler's tuft feeder. This significantly advanced card feeder is called the SCANFEED TF. By controlling the web thickness in both the length and width the feeder enables the continuous flow of a highly even fiber feed. Control in length is often referred to as the control in the machine direction or MD and along the width is the cross-machine direction or CD. Two of the main technologies that are employed to create this uniform feed are the self-regulating distribution in width and a web profile control. As fibers are chute feed with the SCANFEED a constant air stream in the feed trunks is used to distribute the fibers evenly across the width. If fibers start to pile up on one side of the feed, the self-regulating air stream takes the path of least resistance and redistributes fibers to the free combing surfaces. This enables an even distribution of fibers across the width to be obtained.[2] A diagram of this can be seen in Figure 7.



[2]

Figure 7: Self-Regulating Distribution in Width of Trützschler Scanfeed

The web profile control of the SCANFEED is the technology exclusive to Trutzschler. This technology controls the web thickness in both width and length with the use of a closed control loop system that permanently checks itself. The deflection of sectional trays is measured below the delivery roll and the signals are converted into a corresponding adjustment.[2] In Figure 8 is a picture of this to better help with the understanding of this innovative concept.



[2]

Figure 8: Web Profile Control of Trützschler Scanfeed

With Trutzschler's SCANFEED nonwoven manufacturers are able to produce significantly more uniform webs. The uniformity is improved so much by this feed system that it is being proposed that the web produced could be fed straight to bonding equipment and bypass the carding machine all together. This would obviously be limited to certain end uses, but will be explored further with this research.

2.2.2. DOA

DOA is a company out of Austria that designs and produces machines for nonwoven manufacturers. They produce bale opener and fiber blending plants, sheet forming plants, scattering devices, needle felting machines, thermal bonding machines and complete nonwoven lines, depending on what is desired by the customer. One innovative machine that they offer is the Bale Opener 920. With this machine, the quantity of fibers from an opened bale being fed into a volumetric feed is controlled. It has an automatic level control, which makes sure that the fiber level always remains constant at the feed. This enables the pre-adjusted layer of fiber to run continuously across an electronic weighing device, which also adjusts the fiber quantity to the desired amount. By controlling the fiber quantity electronically there is less room for error, providing for more consistent quality. Two images of the Bale Opener 920 can be found in Figure 9.[10]


[10]

Figure 9: DOA's Bale Opener 920

2.2.3. Temafa

Temafa is a German manufacturer of preparatory machines for opening, blending, and cleaning of synthetic as well as natural fibers. They offer a wide range of machines and systems as well as material handling solutions. One particularly advanced blending system that they offer is the BALTROMIX system. The BALTROMIX system utilizes a fiber blending technique based on the composition of pre-selected batches controlled from a central control unit. The composition of the batches as well as the specific machine settings can be programmed through this central control unit. This unit activates the required machine parameters for each corresponding machine being used within the system. The input of the bales is controlled by the WEIGHT MASTER, which is also controlled by the central control unit. This unit not only offers pre-calculated blending but also operational convenience. Statistical analysis of all the process data is provided including, CV values, shift reports, and raw material reports.[36]

2.2.4. Ommi S.p.A.

Ommi S.p.A. produces plants and machines for the textile industry. They were the first Italian builder of blending plants, and currently provide blending machines for the nonwovens industry. One particular technology they have to offer is the automatic bin emptier. This automatic emptying unit moves into the blending bin and removes the fibers. This is done by vertical slides and a heavy duty spiked apron. The machine and emptying model are depicted in the images in Figure 10. The bin emptier runs on underground rails and is four-wheel driven. A brushless motor through a chain drive powers the four wheels. This assures a constant torque and perfect control of the running speed of the machine. A set of proximity sensors also automatically centers the machine in the proper position. A control panel allows total programming of the performance of the emptier.[25]

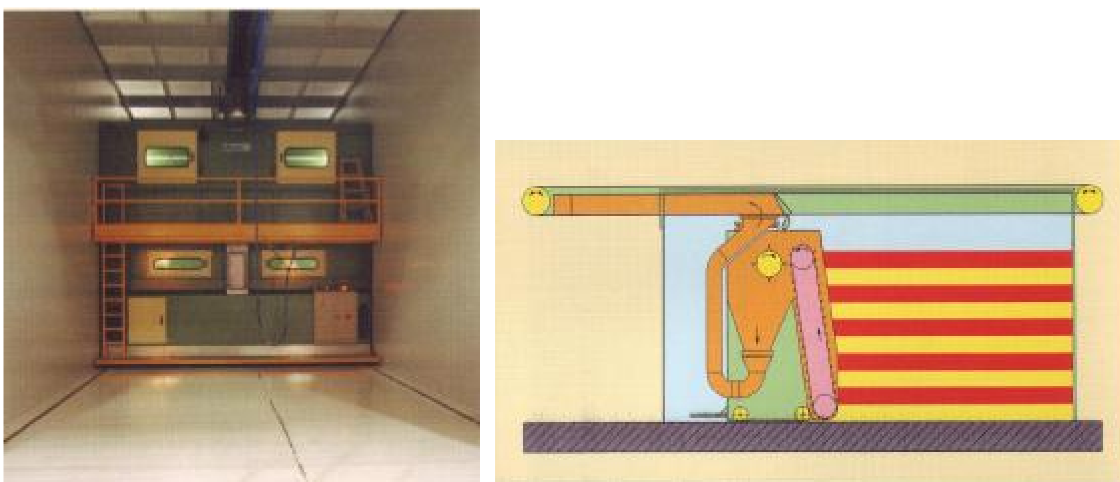

[25]

Figure 10: Ommi S.p.A.'s Automatic Bin Emptier

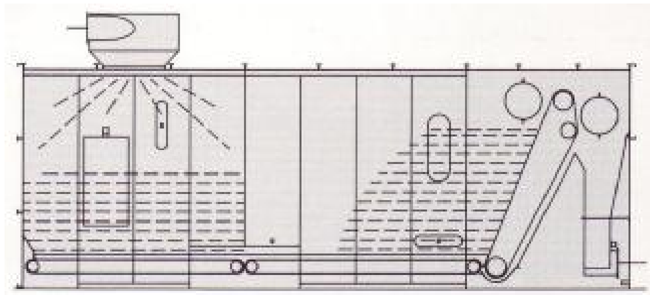
This type of bin emptier is used in batch blending or sometimes for bale blending prior to repackaging. As can be seen in the image, the bin emptier sweeps out the entire fiber lot so this machine is not used when continuous blending is desired.

A central electric control panel controls all of Ommi S.p.A.'s blending lines and is displayed by either a synoptic board or a color/monochromatic monitor controlled by a computer. The centralized control panel allows for the automatic or manual selection of a particular cycle to be performed. It also allows for the sequential starting of the plant, either manual or automatic, and the control of single machine operations.[25]

2.2.5. Pneumatic Conveyors

Pneumatic Conveyors is another company that offers fiber opening and blending machines for the nonwoven industry. The machinery is manufactured under a license by Signal Machine Company, Inc. of Georgia and sold by Ford, Trimble & Associates. One particular machine they offer for staple fiber processing is their weigh hopper. Pneumatic Conveyors' weigh hoppers enable accurate input of fiber by weight into blending machines. Their weigh hoppers use load cell type weighing to ensure accuracy. The machines are interfaced with computer control panels for easy recipe settings. This is crucial to make sure that a process can be repeated every time with the exact same parameters, ensuring that consistent quality products are produced.[27]

Pneumatic Conveyors also offers an Automix Bin that is used for continuous accumulation of fibers, which are then mixed using a metering line and automatically fed to a card. The Automix bin has a special dual section design that provides continuous horizontal layering of the fibers and then vertical slicing of the sub lots. This concept is depicted in Figure 11. The Automix bin is remotely controlled from an input line control system. This control system can allow a single production line to alternatively refill several Automix bins serving different cards. The extreme mixing and flexibility of the Automix bin offers more options for nonwoven producers to improve their web quality.[28]



[27]

Figure 11: Pneumatic Conveyors' Automix Bin

Another machine Pneumatic Conveyors has to offer is their card feed towers, which allow for the automatic transfer of blended fiber into the card hopper. There are controls that automatically maintain the card hopper level ensuring accurate fiber input into the card as well as automatic replenishment of the feed tower from the blending plant. By the entire feed system being automatic and remotely controlled, the risk of contamination associated with manually feeding the card hoppers is removed.[27]

2.2.6. ERKO-Trutzschler

ERKO-Trutzschler, formally ERKO Textile Machinery Ltd, manufactures complete electric and electronic control systems for textile machinery like those described above. In January 2006 they merged with Trutzschler to form ERKO-Trutzschler Nonwoven Ltd. ERKO-Trutzschler markets the most up-to-date control systems for nonwoven machines. They enable machines to be easily managed. Their control systems provide digital status reports during production along with complete display presentations enabling accurate fiber processing and smooth web production. Another feature that their control systems offer is the ability for production lines to be serviced worldwide using integrated modems to diagnose system failures. Failures can be diagnosed even down to individual motor performance. Not only do they design these control systems for new machines but they can also modernize nonwovens machines by any maker. They do this by installing modern driving systems as well as electric and electronic controls. Since the nonwovens industry produces such technical fabrics with very little human assistance the need for advanced control systems has almost become a necessity. This is especially true for the preparatory equipment, since the exact optimization of each function is so crucial to producing a quality product. ERKO-Trutzschler is providing these control systems for machines across the industry.[12]

2.3. An Ideal Web

Through the use of the machines and technology described above, web quality of nonwovens has been greatly improved in the past years. But what determines web quality? With adequate preparatory processing, an ideal feed to the card would have a uniform web density across both width and length, a uniform distribution of fibers in the fiber mix if two or more types of fibers are used, the absence or low occurrence of fiber neps, low fiber breakage, and the absence of repeat patterns of creases or thick and thin section across the web.[9] The variation in web opacity is also of significance and is associated with differing openness. These web characteristics all help to determine the quality of the web fed to the card and therefore also the final web quality of the nonwoven. Uniform density and low fiber damage are of significant importance when investigating the influence of the preparatory equipment on the web quality and will be assessed in the research.

3. DESIGN OF EXPERIMENTS

The purpose of this research is to analyze the influence of staple fiber preparatory equipment and explore the possibility of creating a staple fiber nonwoven with only this equipment, completely by passing the traditional use of a card and crosslapper. The main idea is to collect samples after each processing stage and, with a chosen set of tests, assess each machine's influence.

3.1. First Preliminary Trial

A set of preliminary trials was conducted to determine the fibers, tests, and machine combinations to be used in the main experiment. The first preliminary trial conducted used three different fiber types: a 1.2 denier PET, a 1.5 denier PET and a 3.2 denier Visil fiber. The machines used were a bale opener, mixer, fine opener, card, crosslapper, preneedler, and needleloom. A flow chart of the machines used can be found in Figure 12.

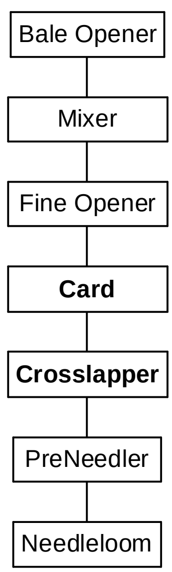


Figure 12: Machine Flow Chart for First Preliminary Trial

For this trial run 15 pounds of each fiber were run through the machines twice. The first time the 15 pounds of fiber was allowed to pass straight through all machines. Samples were collected after each machine and documented accordingly. For the second pass, the fiber cycled through the mixer for 15 minutes before continuing through all other machines. Samples were again collected and documented after each machine. Several different tests for assessing the fiber properties were explored with the samples collected.

During the first preliminary trial, the Favimat testing instrument was the primary instrument investigated. It was hoped that the Favimat could be used to measure changes in fiber properties, but the fiber fineness data conflicted with the manufacturer's specifications. To make sure that it was the Favimat instrument, and not the fiber specifications, that was erroneous, the fibers were tested using the Vibromat, a testing instrument that uses resonance frequency to measure individual fiber fineness.[34] The fibers were also examined with an optical microscope in order to calculate their denier through fiber width measurements. All fiber fineness measurements can be found in Table 2.

Table 2: Fiber Fineness Findings (denier)

	PET 1	PET 2	Visil
Manufacturer's Specifications	1.2	1.5	3.2
Favimat	5.17	7.25	11.68
Vibromat	1.28	1.44	3.25
Optical Microscope	1.29	1.37	3.11

After it became evident that the Favimat Instrument was indeed erroneous and since the denier results were used to evaluate tenacity, doubt was thrown on most of the reported data. Following this study and based on the data obtained in Table 2, the machine was recalibrated by the manufacturer. Other fiber testing instruments were considered during this preliminary trial, but it was concluded that the Favimat was the most advantageous machine, as long as the denier measurements were corrected with the calibration.

One particular instrument considered was the Advanced Fiber Information System (AFIS), manufactured by Uster Technologies. The advantage of this instrument is that it measure many individual fibers and then reports the mean and variation of the fiber length, fineness, and nep content.[1] This instrument would have been ideal for the experiment but after consultation with industry members and academic experts it was concluded that AFIS is only accurate when using natural fibers, particularly cotton. The testing of man-made fibers typically results in inaccurate measurements if the machine does not jam and stop working all together. At one point, Uster manufactured an AFIS machine to test PET but because of low demand it was discontinued. An effort was made to locate one of these machines, but to no avail, although it was reported that the machine could only be reliable for comparative analysis at best. Since one of the reasons the AFIS machine was desirable was its ability to measure fiber length and variation, it was decided to use the Peyer FL101/AL101 testing instrument instead.

3.2. Second Preliminary Trial

The second preliminary trial conducted used two different fiber types: the same 1.5 denier PET fiber from the first trial as well as a 1.3 denier PLA fiber. Instead of the traditional method of creating a needlepunched nonwoven with a card and crosslapper like before, the scanfeed machine was used. The machines used for the second preliminary trial were a bale opener, mixer, fine opener, scanfeed, preneedler and needleloom. A flow chart of the processing machines used in the second preliminary trial can be found in Figure 13.

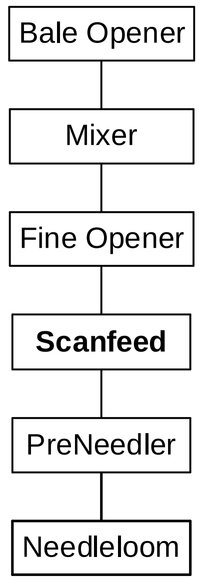


Figure 13: Machine Flow Chart for Second Preliminary Trial

For this preliminary trial 50 pounds of each fiber was processed through the machines twice. For the first run, the fibers were processed straight through all the machines, with samples being collected after each machine. For the second run, the fibers were mixed for 15 minutes in the mixer before being processed by the remaining machines. Again samples were collected after each machine. Not only were fiber samples collected after the bale opener, mixer and fine opener, but web samples were collected after the scanfeed and preneedler and fabric after the needleloom.

The fiber samples were tested using the newly calibrated Favimat machine. The results were promising, with the fiber fineness findings much closer to the manufacturer's specifications. The measured tensile properties from the PET fibers seemed to decline as processing increased while less change was observed with the PLA fibers. This can be observed in Figure 14. It was concluded from these tests that the Favimat instrument would be used in the final experiment.

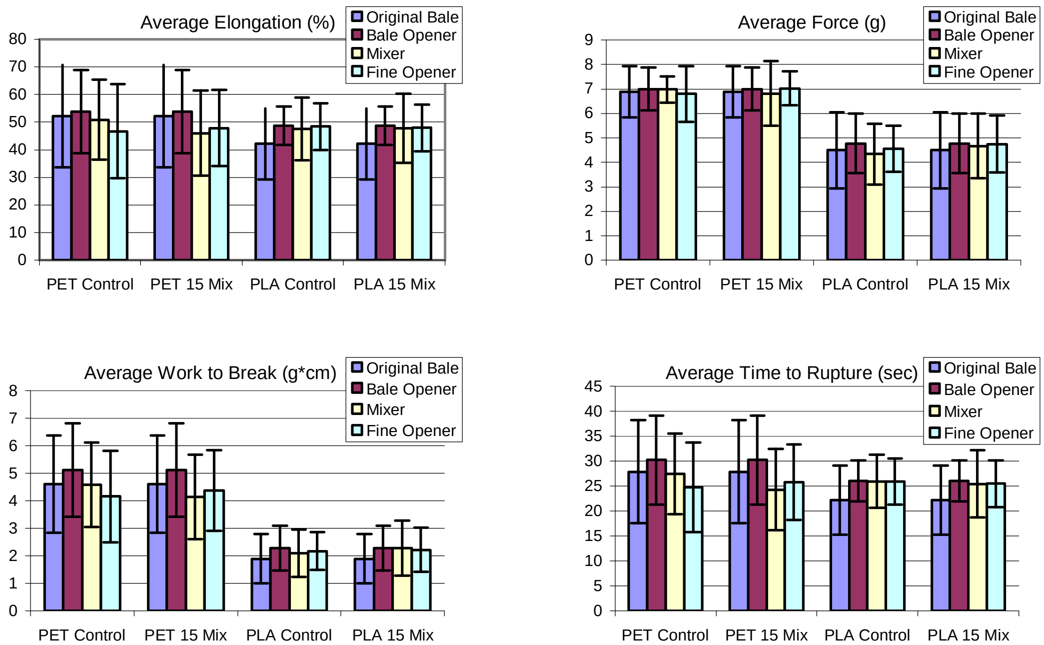


Figure 14: Measured Tensile Properties of PET and PLA Fibers

Tests to evaluate the web and fabric samples were also investigated. An image analysis program developed by Allasso Industries in conjunction with NCRC was used to assess the uniformity of the samples collected. Both the unbonded web samples and the needlepunched fabric samples from this preliminary trial were scanned using a flatbed scanner and the images analyzed. Originally this program was only capable of producing one uniformity number for the entire square image analyzed. It was proposed to have the program modified so that the exact same square image could be analyzed not only as a whole, but also by different square sizes. Much time was spent working out the ‘bugs’ of the newly altered program in order to have it report the desired figures in a decipherable manner. After this was accomplished, the original 8x8” images were also analyzed on a 4x4, 2x2, and 1x1” scale.

From the testing it was found that the web samples collected after the scanfeed and preneedler were not entangled enough to withstand the handling required between sample collection, storing and scanning. Despite extreme attempts to keep the webs unaltered it was found to be near impossible. Because of this, the uniformity numbers produced from the web samples were assumed unreliable. The uniformity analysis of the fabric samples, on the other hand, was very encouraging. It was decided from the results observed that this testing method would also be used in the final experiment to asses the uniformity of the fabric samples produced.

When scanning the fabric samples for image analysis the image resolution is an important factor. The uniformity numbers produced are affected by the amount of pixels per inch (ppi). The total time it takes to scan and analyze the image is also affected by the ppi. For the preliminary trial a resolution of 400 ppi was initially used. Before conducting the tests for the final experiment several analyses were performed to decide the best image resolution. Images with 200, 400, 600, and 800 ppi were analyzed and the results assessed. It was ultimately decided to use the 600 ppi resolution despite the increased amount of time it would take to scan and analyze the images. This decision was based on the fact that when analyzing 1x1” squares often times negative uniformity numbers were obtained. By increasing the resolution the amount of negative numbers was decreased. The 800 ppi resolution was not chosen because at this resolution the scanning and analysis time as well as the file size were excessive.

The basis weight method of assessing uniformity was also examined during the second preliminary trial. This involves weighing fabric samples cut from each roll and finding the variation between samples. The weight variation can be used as an indicator of uniformity for the fabrics produced. Fabric samples from the second trial run were cut using a dye cutter and weighed with a digital scale. The measurements were found to be a useful tool for uniformity assessment and since this testing method is used throughout the nonwovens industry, it was also used in the final experiment.

When assessing the uniformity results of the scanfeed fabric produced in the second preliminary trial it became evident that while the results appeared sound, in order to truly asses the scanfeed product the results needed to be compared to a traditional carded/crosslapped nonwoven. It was decided that if the possibility of creating a staple nonwoven with unconventional methods were to be explored, fabrics must also be made the traditional way (with a card and crosslapper) using the same parameters, so that the two could be compared. An experimental design incorporating this concept was created for the final processing trial.

3.3. Fibers

Two different fibers were used in the main experiment. The first fiber chosen was a 1.2 denier PET from Wellman. It was from a ‘first quality bale’ with mid-tenacity and 30 percent crimp (11 CPLI). This fiber, S-D type 203, was designed specifically for nonwoven applications and has a finish chemistry with good lubrication and static protection. The length of the fiber is 1.5 inches. This particular fiber was chosen because it is frequently used throughout the industry in nonwoven production and thus represents a commonly processed fiber.

The second fiber used in the experiment is Visil, a flame retardant viscose fiber. It is of great interest to industry members because it is a biodegradable, flame retardant fiber. Unlike most other types of fire-resistant fibers, Visil is environmentally friendly, does not melt or flow when in contact with heat or flame and does not emit smoke or toxic gases according to ASTM E 1354-90. The fiber is widely used in flame retardant mattresses,[32] but has proven to be a tough fiber to process with staple fiber machinery. For this reason, Visil was chosen as the second fiber to use in our research experiments.

The specific Visil fiber used in the experiment is 3.2 denier and 2 inches in length. It is made up of 65-75% regenerated cellulose, 25-35% silicic acid and 2-5% aluminum hydroxide. The fiber has a tenacity of 1.3 ± 0.2 cN/dtex, an elongation of 21 ± 5 %, and a finishing agent application of 0.9 ± 0.3%. The fiber is exclusively made by Sateri International Group, a company out of Finland.

3.4. Processing Experiment

The main processing trial was conducted in the nonwovens staple laboratory using the PET and Visil fibers described above. Six individual processing runs were conducted, three for each fiber. One hundred and forty pounds of fiber were processed through the machines on each run. Each of the six processing runs were made into two different types of nonwoven fabric rolls. The first nonwoven fabric made was a typical needlepunched nonwoven using the card and crosslapper. The second nonwoven fabric was made from the same processed fiber as the first but instead of using the card and crosslapper the fiber was processed by the scanfeed and then sent straight to the needlepunch machines. A flow chart of the processing machines used for each trial run can be found in Figure 15.

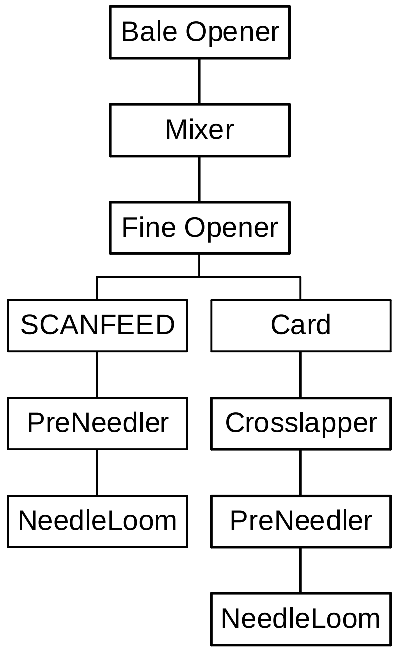


Figure 15: Flow Chart of Machines Used in Experimental Trials

Table 3 describes the exact machines used and their production capabilities.

Table 3: Staple Fiber Processing Machines Used in Experimental Trials

	Machine	Capabilities
Bale Opener	Truetzschler Bale Opener BO	Maximum Input: 1000 kg/hr Maximum Output: 1200 kg/hr
Mixer	Truetzschler Blending Hopper BOSL	Maximum Intake: 2040 kg/hr Maximum Output: 1700 kg/hr
Fine Opener	Truetzschler Fine Opener FOL	Maximum Output: 2000 kg/hr
Scanfeed	Truetzschler Scanfeed	Maximum Throughput: 400 kg/hr Fiber Range: 2 to 4 inches/ 0.5 to 2.0 denier Web Weights: 300 to 1500 gsm Web Width: 1.5 meters
Card	Truetzschler DK-903 Card	Maximum delivery speed: 25 m/min Fiber Range: 1 to 4 inches/ .6 to 2.0 denier Web Weights: 8 to 20 gsm Web Width: 40 inches
Crosslapper	Asselin P415 Profile Crosslapper	Minimum input: 5 m/min Maximum input 100 m/min Maximum oupt: 40 m/min Delivery web width: 0.6 to 1.5 meters
Pre-needler	Asselin 169 Pre-needler Type: Double Board	Minimum input/output: 0.1 m/min Maximum input/output: 7.4 m/min Needle board: 8 needles per square inch
Needleloom	Shoou Shyng SNP-120 Needle Loom Type: Single Board	Input/Output speeds: 2 to 6 m/min Maximum strokes: 1500 Needle board: 16 needles per square inch [24]

Both the PET and Visil were individually run through the machines three times. For the first pass, the fiber was processed straight through all the machines represented in the flow chart [Figure 15]. Fiber samples were collected after each machine and documented accordingly. For the second pass of each fiber, 140 more pounds were run through the machines. This time the fiber was cycled through the mixer for 45 minutes before continuing through the rest of the machines. Again fiber samples were gathered after each stage of processing and marked accordingly. The third pass of each fiber was conducted the same as the previous two, except the fiber was allowed to cycle through the mixer for 90 minutes. Fiber samples were again collected and documented after each machine. The two images in Figure 16, depict the blending machine used for the cycling of fibers for different mixing amounts in the processing trials.

Figure 16: Trützschler Blending Hooper in the Nonwovens Staple Laboratory

The fabric rolls produced from each run were collected after the needlepunch machine and labeled. Overall, twelve fabric rolls were produced from the two different fibers. Table 4 and 5 describe the entire processing trial for both the PET and Visil fiber.

Table 4: Configuration of Experimental Runs for PET

Run	Fabric Roll	Mixing Amount			Web Forming Machine	
		Ctrl	45 Mins	90 Mins	Scanfeed	Card/Crosslap
1	1	X			X	
	2	X				X
2	3		X		X	
	4		X			X
3	5			X	X	
	6			X		X

Table 5: Configuration of Experimental Runs for Visil

Run	Fabric Roll	Mixing Amount			Web Forming Machine	
		Ctrl	45 Mins	90 Mins	Scanfeed	Card/Crosslap
4	7	X			X	
	8	X				X
5	9		X		X	
	10		X			X
6	11			X	X	
	12			X		X

Since fiber properties such as denier, length, strength, crimp, and finish have a huge influence on processing ability the experimental design was set up to consider the two different fiber types as individual experiments. This will enable each machines' influence to be assessed accurately.

Table 6: Variable and Constant Parameters for PET Trials

Parameters	Constant	Variable
Machine Settings	X	
Production Speeds	X	
Mixing Amount		X
Web Forming Machine		X
Amount of Fiber	X	
Fiber Properties	X	

Table 7: Variable and Constant Parameters for Visil Trials

Parameters	Constant	Variable
Machine Settings	X	
Productions Speeds	X	
Mixing Amount		X
Web Forming Machine		X
Amount of Fiber	X	
Fiber Properties	X	

3.5. Testing Procedures

Several testing methods were used to assess fiber and web properties in order to analyze the effects of each processing machine. After careful consideration of many fiber and web testing methods, four tests were chosen, two for fiber assessment and two for web assessment. A great deal of emphasis was placed on the uniformity image analysis program and further developing its capabilities.

3.5.1. The Favimat

Stressing of fibers in preparatory processing can exert a considerable negative influence on fiber characteristics, especially strength, elasticity and fiber length.[21] Fiber properties such as fiber strength, fiber fineness and fiber stress-strain properties can be measured using Textechno's Favimat instrument, which can be seen in Figure 17.

Figure 17: Favimat Testing Instrument

For this experiment the Favimat machine was used to measure the fiber properties before and after each processing stage. Table 8 shows exactly where fiber samples were collected throughout the processing trials.

Table 8: Fiber Sample Collection Sites

	Original Bale	Bale Opener	Mixer	Fine Opener	SCANFEED	Card
PET Ctrl	X	X	X	X	X	X
PET 45Mix			X	X	X	X
PET 90Mix			X	X	X	X
VIS Ctrl	X	X	X	X	X	X
VIS 45Mix			X	X	X	X
VIS 90Mix			X	X	X	X

As can be seen a total of 28 fiber samples were collected and tested. Since the mixing variable was not introduced until the blending machine, only one sample batch from the original bale and bale opener were tested for each fiber type. Fifty fibers from each sampling were evaluated using the Favimat, meaning a total of 1400 fibers were tested.

To use the Favimat and find fiber properties the fibers must first be separated into single individual fibers. This is done very carefully with tweezers over black felt. A small blue sticky tab is placed on the end of each fiber to keep them separate, identified and to add a minute amount of weight for machine loading. Preparing the fibers for testing is a very tedious process and must be done with care so not to alter the properties of the fiber. After the filaments are separated they are then tested one at a time. For each test, a single filament is picked up with a pair of tweezers and loaded into the machine's small clamps. The gauge length is variable from 5 to 100mm.[3] For this experiment the gauge length was set to 14mm. Once aligned between the clamps, the continue button on the machine is pressed three times. The first time closes the top clamp, the second time the bottom clamp, and the third closes the machine door, which keeps environmental influences out. The property testing begins and the results are reported on the computer screen.

The Favimat measures fiber fineness according to the vibroscopic ASTM D 1577 standard with a built in automatic measuring head. The fiber is loaded to a predetermined specific tension at a predefined speed. The fiber is excited with an electro acoustic sinusoidal vibration and an optoelectronic sensor detects resonance frequency.[11] The formula used to calculate the fiber count is as follows.

[11]

$$T_t = \frac{F_v \times 10^{11}}{4 \times f^2 \times L^2}$$

T_t = Fineness in dtex

F_v = Pre-tensioning force in cN

f = Resonance frequency in Hz

L = Testing Length in mm.

Uniform mass distribution and a circular cross-section are assumed while the bending rigidity is disregarded in order to simplify the calculation.[11]

The fiber strength properties are derived from the peak load of each fiber. When the fiber is mounted between the two clamps of the machine, it is loaded until it breaks. If the test is set to also measure crimp, the fiber is loaded until its crimp is removed, released to its original position and then loaded again until its breaking point.[11]

3.5.2. Peyer FL101/AL-101

The Peyer FL101/AL101 Texlab system measures fiber length distribution and can be used before and after processing to indicate fiber damage. The machine consists of two parts, the Fibroliner (FL-101) which is a mechanical comber and alignment machine and the Almeter (AL-101) which is a capacitive sensing machine.[31] The FL-101 part of the machine sorts and aligns the fiber sample by mechanically combing the fibers into a parallel bundle. The aligned fibers are then placed between a pair of carrier films to be measured by the AL-101 part of the machine. The AL-101 scans the fiber bundle using capacitance measurements and produces and output signal that is proportional to the mass distribution.[17] The capacitor scans the sample every 0.125 millimeters and forms fiber classes. The measuring principle of the machine is based on the wedge shape of the fiber bundle from the greater number of shorter fibers after being aligned. This principle is based on the assumption that all fibers have the same fineness.[33] Fiber bundles from all 28 samples taken from the processing trial were tested in the Peyer machine. It takes about 15 to 20 minutes to test a sample on the Peyer testing machine. Figure 18 shows the main components of the Peyer Texlab system.


[8]

Figure 18: Peyer FL101/AL101 Texlab System

3.5.3. Uniformity Image Analysis

The uniformity of a nonwoven is significant because it can influence the 'average' properties of the fabric, like tensile and tear strength, and predict how it will perform when used in specific applications. Uniformity can be quantified using several different methods. For this experiment two testing methods will be used, the first is image analysis. To perform this test, thirty 15x22" fabric samples were cut from each of the twelve rolls produced.

A large flatbed scanner was used to transmit light through each sample and determine the mass uniformity, which correlates to basis weight. The thirty 15x22" samples from each roll were placed on the scanner and their image was scanned using transmitted light at 600 dots per inch. As the light is sent through the sample it losses intensity as it goes through mass. Any mass non-uniformity found by the scanner results in variations of brightness of the image.[11] The thicker the mass the darker the pixel in the image will be. This can be seen in the samples of fabric images in Figure 19, captured with the flatbed scanner used for testing.

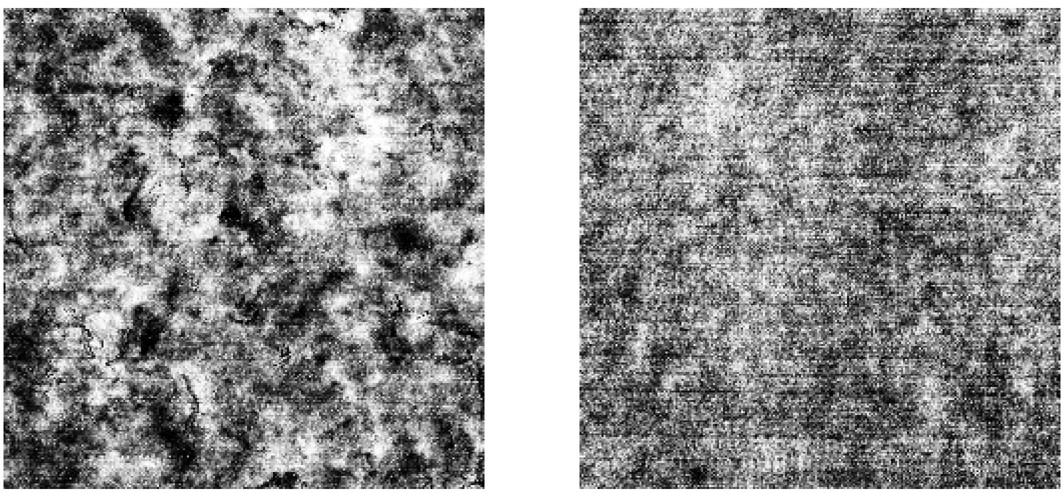


Figure 19: Images of Fabric Samples Scanned using a Flatbed Scanner

A square image is needed for image analysis so an 8x8" image was taken from the 15x22" sample and saved on file. The resulting images were analyzed using an uniformity analysis program developed by NCRC in conjunction with Allassso Industries. This program measures mass uniformity by quantifying the mass variation in the sample image. A uniformity number is given for each sample analyzed, representing the level of uniformity up to 100, which represents perfect uniformity. To determine the uniformity index describing the data, it is normalized as follows:

$$\text{Uniformity Index} = \left(1 - \frac{\sum_{i=2}^{i=n} c_i^2}{\sum_{i=2}^{i=n} (N_i - 1) c_{\max}} \right) \text{x100} \tag{11}$$

$$\text{Where } c_{\max} = 1$$

Since 30 samples were scanned from each of the twelve rolls, a total of 360 images were scanned into the computer and analyzed using the uniformity image analysis program. The scanner used for this is shown in Figure 20.

Figure 20: Flatbed Scanner Used to Capture Web Images

After running the 8x8" images through the analysis program and finding the uniformity number of each sample the program was altered so that the images could be split by rows and columns, enabling smaller square portions of the same sample to be analyzed. Since the smallest area capable of being analyzed by this software is a 1x1" square, we first split the 8x8" images into 64 one-inch squares. The image analysis works best with squares, so we then analyzed 2x2" squares, creating 16 squares out of the original 8x8" images. Lastly the sample images were divided into 4x4" squares, creating

4 squares. All of these were analyzed for uniformity. Figure 21 depicts how the sample images were divided and analyzed in the uniformity program.

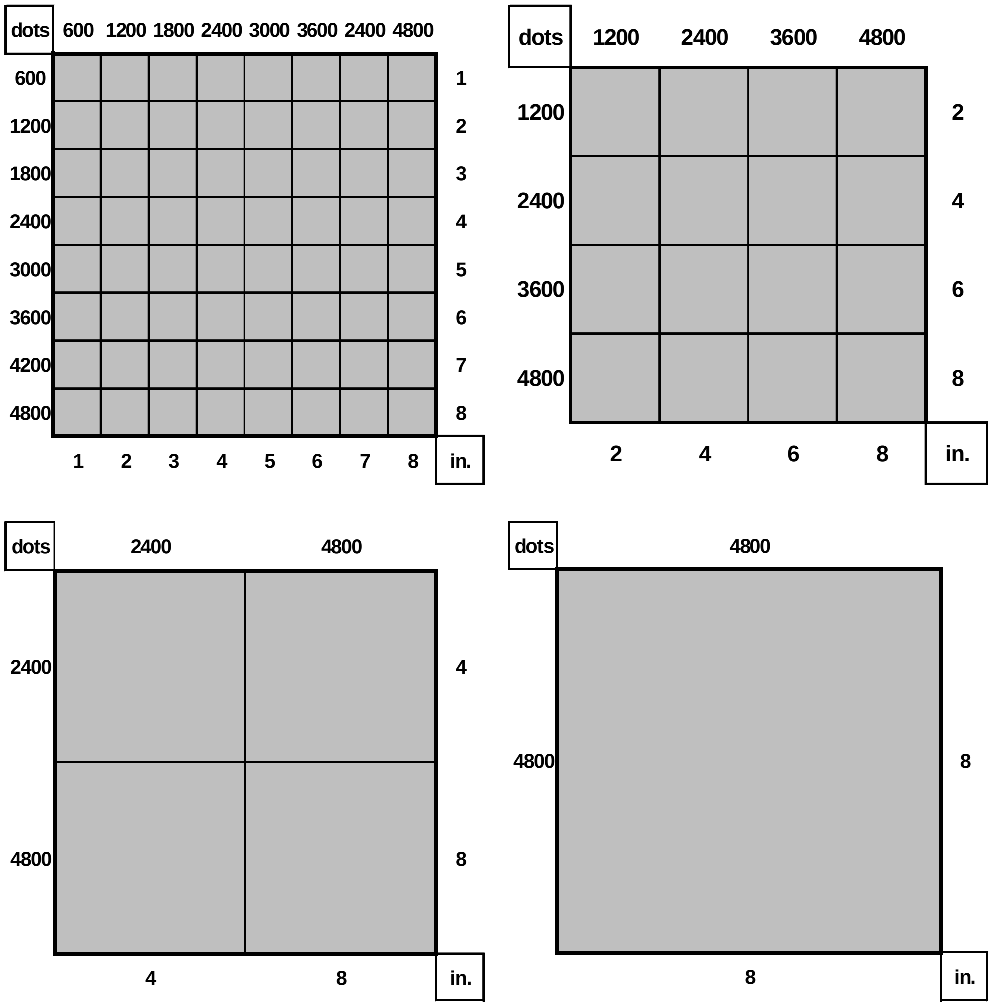


Figure 21: Division of Images for Uniformity Analysis

A uniformity number was produced for each square in each example. All 360-fabric images were divided these four ways and each individual square analyzed. The resulting data shows not only the uniformity of the overall samples and the mass variation within the samples, but also by analyzing different size squares the size of fiber masses present can be seen.

3.5.4. Basis Weight Uniformity

Basis weight uniformity indicates how uniform or non-uniform the basis weight of a nonwoven between the web samples measured. In this test, fabric samples were cut and weighed in order to measure the variation in basis weight. Three 4x4" fabric squares were cut from each 15x22" fabric samples previously scanned for image analysis, meaning a total of 90 samples were weighed from each roll. The 4x4 squares were cut using a dye cutter to ensure a consistent fabric size. These squares were individually weighed using a digital scale and then converted to grams per square meter.

By weighing these samples two things can be observed. First, the variation of basis weights between samples can reveal the uniformity of the fabric rolls produced. If the basis weight varies a great deal between samples from the same roll, this indicates that the fiber is not distributed evenly and the web uniformity is poor. These results can then be compared to the image analysis results. Secondly when looking at the basis weight of scanfeed fabrics, a difference in average basis weight from roll to roll can be used as an indication of openness, since all machine parameters were kept the same. The scanfeed machine distributes fiber amount based on volume instead of weight, so if a fabric is produced with fibers that are not adequately opened it will be much heavier fabric than a fabric produced with fibers that have been adequately opened. While the fiber volume would be the same, the unopened fibers would be clumped together in large tufts weighing much more than the adequately opened, bulky fiber mix.

4. RESULTS AND DISCUSSION

This chapter presents the results from the tests conducted on the samples collected from the experimental trials. These tests were intended to assess the effect of each processing machine and the mixing amount on fiber properties and web uniformity. They were also used to compare the nonwoven fabrics made with only preparatory equipment to the ones made by the traditional carding/crosslapping method.

The data collected from the tests were analyzed using SAS statistical analysis software. The main analysis used to evaluate the tests results was ANOVA, which compares the means of data sets and indicates whether they are significantly similar or different. This statistical procedure tests the null hypothesis, that the means are not significantly different, against the alternative hypothesis, that the means compared are significantly different. The tables represented in this chapter show the results of the ANOVA tests in the form of the F-statistic and P-value. An alpha level of 0.05 was used, so when the p-value is found to be greater than 0.05 than we do not reject the null hypothesis and conclude with a 95% confidence level that the means are insignificantly different.

When a significant difference was found and more than two means were being compared, pairwise comparisons were made using Fisher's Least Significant Difference (LSD) method. With this analysis method, a LSD number is computed using the formula $LSD_{ij} = (t_{\alpha/2,\ N-t})\ \sqrt{MSE(1/n_i + 1/n_j)}$.[26] The next step is to compute all pair wise differences of sample means. This is performed by taking two sample means and finding the difference between them. This difference is then compared to the LSD number. If the difference of the samples means is greater than the LSD number than we conclude that the two paired means are significantly different.

4.1 <u>Favimat Results</u>

The following data was collected from the Favimat and statistically analyzed. The results were used to look at the effect of each processing machine and mixing amount on fiber properties.

4.1.1. Effect of Processing Machine

The first statistical analysis run was to compare the effect of each processing machine on web properties. The data used in this analysis was from the Favimat test conducted on single filament fibers collected from each processing machine during each trial run. The results of the analysis are split up by fiber. The properties of the two fibers are inherently different and therefore the results will be examined separately.

4.1.1.1. PET Fiber

Table 9–11 show the mean fiber property values, reported by the Favimat, for the PET fibers collected. The tables are split up by the three mixing amounts. The machine abbreviations are as follows: Bale = Original Bale, BO = Bale Opener, FO = Fine Opener, SF = Scanfeed, and Card = Card. The mean values for the original bale and bale opener are the same in all three tables, since the mixing amount did not affect these fibers. The EASF-5g values represent the Elongation at a Set Force, which is 5 grams. The FASE-10% values represent the Force at a Set Elongation, which is 10 percent.

Table 9: Processing Machine Influence on PET Control Fiber

PET - Control	Bale	BO	Mix	FO	SF	Card	ANOVA			
	Mean	Mean	Mean	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	45.34	46.32	46.91	47.46	44.86	41.16	1.55	0.1753	Insignificant	-
Force	5.68	5.83	5.81	5.73	5.68	5.54	1.30	0.2651	Insignificant	-
Tenacity	3.83	3.82	4.14	4.09	4.08	4.07	1.52	0.1842	Insignificant	-
Work	3.24	3.51	3.59	3.52	3.34	2.95	1.91	0.0927	Insignificant	-
Time	23.66	25.42	24.91	25.20	24.46	22.63	1.20	0.3094	Insignificant	-
Denier	**1.58**	**1.60**	**1.46**	**1.46**	**1.44**	**1.39**	**2.84**	**0.0161**	**Significant**	**0.1398**
EASF-5g	24.89	22.25	25.26	27.41	23.19	22.11	1.23	0.2955	Insignificant	-
FASE-10%	3.23	3.03	3.47	3.30	3.31	3.29	1.60	0.1607	Insignificant	-

Table 10: Processing Machine Influence on PET 45 Mix Fiber

PET - 45 Mix	Bale	BO	Mix	FO	SF	Card	ANOVA			
	Mean	Mean	Mean	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	45.34	46.32	43.28	44.47	44.90	41.31	1.04	0.3929	Insignificant	-
Force	5.68	5.83	5.69	5.74	5.74	5.59	0.69	0.6344	Insignificant	-
Tenacity	3.83	3.82	4.08	3.88	4.11	4.09	1.24	0.2900	Insignificant	-
Work	3.24	3.51	3.18	3.35	3.39	2.99	1.24	0.2900	Insignificant	-
Time	23.66	25.42	22.88	23.62	23.69	22.31	1.31	0.2617	Insignificant	-
Denier	**1.58**	**1.60**	**1.46**	**1.57**	**1.45**	**1.40**	**2.57**	**0.0268**	**Significant**	**0.1454**
EASF-5g	24.89	22.25	21.94	22.19	24.48	22.21	0.52	0.7645	Insignificant	-
FASE-10%	**3.23**	**3.03**	**3.53**	**3.51**	**3.49**	**3.29**	**2.82**	**0.0167**	**Significant**	**0.3302**

Table 11: Processing Machine Influence on PET 90 Mix Fiber

PET - 90 Mix	Bale	BO	Mix	FO	SF	Card	ANOVA			
	Mean	Mean	Mean	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	45.34	46.32	46.00	48.70	47.19	40.93	2.16	0.0586	Insignificant	-
Force	5.68	5.83	5.63	5.71	5.67	5.58	0.88	0.4921	Insignificant	-
Tenacity	3.83	3.82	4.06	3.93	3.91	4.02	0.66	0.6551	Insignificant	-
Work	**3.24**	**3.51**	**3.33**	**3.60**	**3.42**	**2.89**	**2.49**	**0.0313**	**Significant**	**0.4396**
Time	**23.66**	**25.42**	**24.85**	**25.91**	**25.17**	**21.89**	**2.43**	**0.0355**	**Significant**	**2.6400**
Denier	1.58	1.60	1.44	1.54	1.53	1.43	1.82	0.1083	Insignificant	-
EASF-5g	**24.89**	**22.25**	**25.83**	**28.47**	**31.93**	**23.01**	**3.02**	**0.0114**	**Significant**	**5.4771**
FASE-10%	3.23	3.03	3.19	3.35	3.23	3.30	0.81	0.5401	Insignificant	-

From the three tables it can be seen that the only means found to be significantly different are the linear density of the fibers from the PET Control and 45 Mix trial run, the FASE-10% for the PET 45 Mix trial run and the work to break, time to rupture and EASF-5g from the PET 90 Mix run.

The six bar graphs in Figure 22 display the mean values that were found to be significantly different for the PET processing trials.

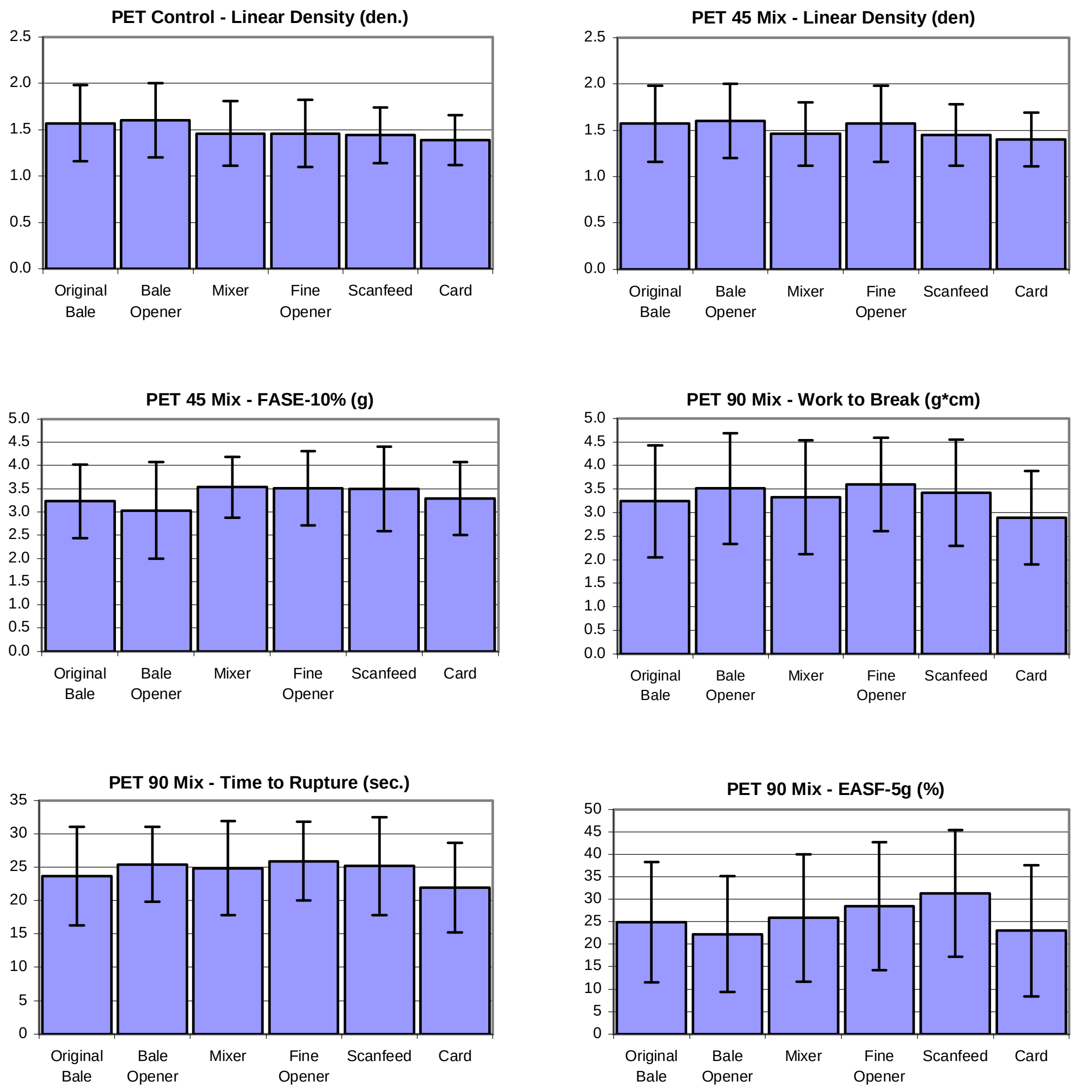


Figure 22: PET Fiber Properties Found to be Significantly Different

In order to see exactly which mean differed the Fisher's LSD procedure was performed. Table 12 reveals the results from the LSD procedure. For most of these properties several means were found to be grouped together with similar means, so the tables help to realize the groupings.

Table 12: Mean Values and Groupings for Significantly Different Fiber Properties

PET Control - Linear Density (den)				
Similar Means			Mean	Machine
A	B		1.58	Original Bale
A			1.60	Bale Opener
	B	C	1.46	Mixer
	B		1.46	Fine Opener
		C	1.44	Scanfeed
		C	1.39	Card

PET 45Mix - Linear Density (den)				
Similar Means			Mean	Machine
A	B		1.58	Original Bale
A			1.60	Bale Opener
A	B	C	1.46	Mixer
A	B		1.57	Fine Opener
	B	C	1.45	Scanfeed
		C	1.40	Card

PET 45 Mix - FASE-10% (g)			
Similar Means		Mean	Machine
A	B	3.23	Original Bale
	B	3.03	Bale Opener
A		3.53	Mixer
A		3.51	Fine Opener
A		3.49	Scanfeed
A	B	3.29	Card

PET 90 Mix - Work to Break (g*cm)			
Similar Means		Means	Machines
A	B	3.24	Original Bale
A		3.51	Bale Opener
A	B	3.33	Mixer
A		3.60	Fine Opener
A		3.42	Scanfeed
	B	2.89	Card

PET 90 Mix - Time to Rupture (sec)			
Similar Means		Means	Machines
A	B	23.66	Original Bale
A		25.42	Bale Opener
A		24.85	Mixer
A		25.91	Fine Opener
A		25.17	Scanfeed
	B	21.89	Card

PET 90 Mix - EASF 5g (%)				
Similar Means			Mean	Machines
	B	C	24.89	Original Bale
		C	22.25	Bale Opener
A	B	C	25.83	Mixer
A	B		28.47	Fine Opener
A			31.30	Scanfeed
	B	C	23.01	Card

This procedure is more easily understood by looking at the PET Control groupings in Table 12. In this table three different groups can be found, Group A, Group B and Group C. Each group represents similar means. If a machine is not included in a group, this means that the fibers' denier from that machine was found to be significantly different from the machines in that group. For example, the original bale and bale opener were found not to be significantly different and thus are grouped together as Group A. The mixer, scanfeed and card were grouped together as Group C since their means were not found to be significantly different as well. In some cases a machine could be in two groups. The mixer was grouped with the scanfeed and card in Group C, but the mixer was also grouped with the original bale and the fine opener in Group B since there was no significant difference found with these machines either.

4.1.1.2. Visil Fiber

Table 13 shows the effects of each processing machine on the Visil fiber as it went straight through all processing machines. From this table we can see that all properties tested except for tenacity and linear density were found to be significantly different.

Table 13: Processing Machine Influence on Visil Control Fiber

VIS - Control	Bale	BO	Mix	FO	SF	Card	ANOVA			
	Mean	Mean	Mean	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	**25.01**	**25.04**	**26.15**	**24.96**	**21.22**	**16.97**	**11.66**	**<.0001**	**Significant**	**2.8524**
Force	**4.79**	**4.75**	**5.06**	**4.71**	**4.76**	**4.29**	**3.16**	**0.0085**	**Significant**	**0.3906**
Tenacity	1.24	1.23	1.32	1.20	1.22	1.08	1.96	0.0841	Insifnificant	-
Work	**1.68**	**1.69**	**1.81**	**1.66**	**1.44**	**1.03**	**10.36**	**<.0001**	**Significant**	**0.2441**
Time	**13.99**	**13.98**	**14.40**	**14.05**	**11.65**	**9.23**	**13.01**	**<.0001**	**Significant**	**1.5796**
Denier	4.08	4.15	4.05	4.21	4.17	4.31	0.38	0.8594	Insifnificant	-
EASF-5g	**7.81**	**10.89**	**13.63**	**9.71**	**8.72**	**3.48**	**4.80**	**0.0003**	**Significant**	**4.3087**
FASE-10%	**3.28**	**3.35**	**3.52**	**3.25**	**3.55**	**2.78**	**2.89**	**0.0144**	**Significant**	**0.4538**

The six bar graphs in Figure 23 depict the mean property values for the Visil Control run which were found to have significantly different means. When looking at these graphs the differing values become more evident.

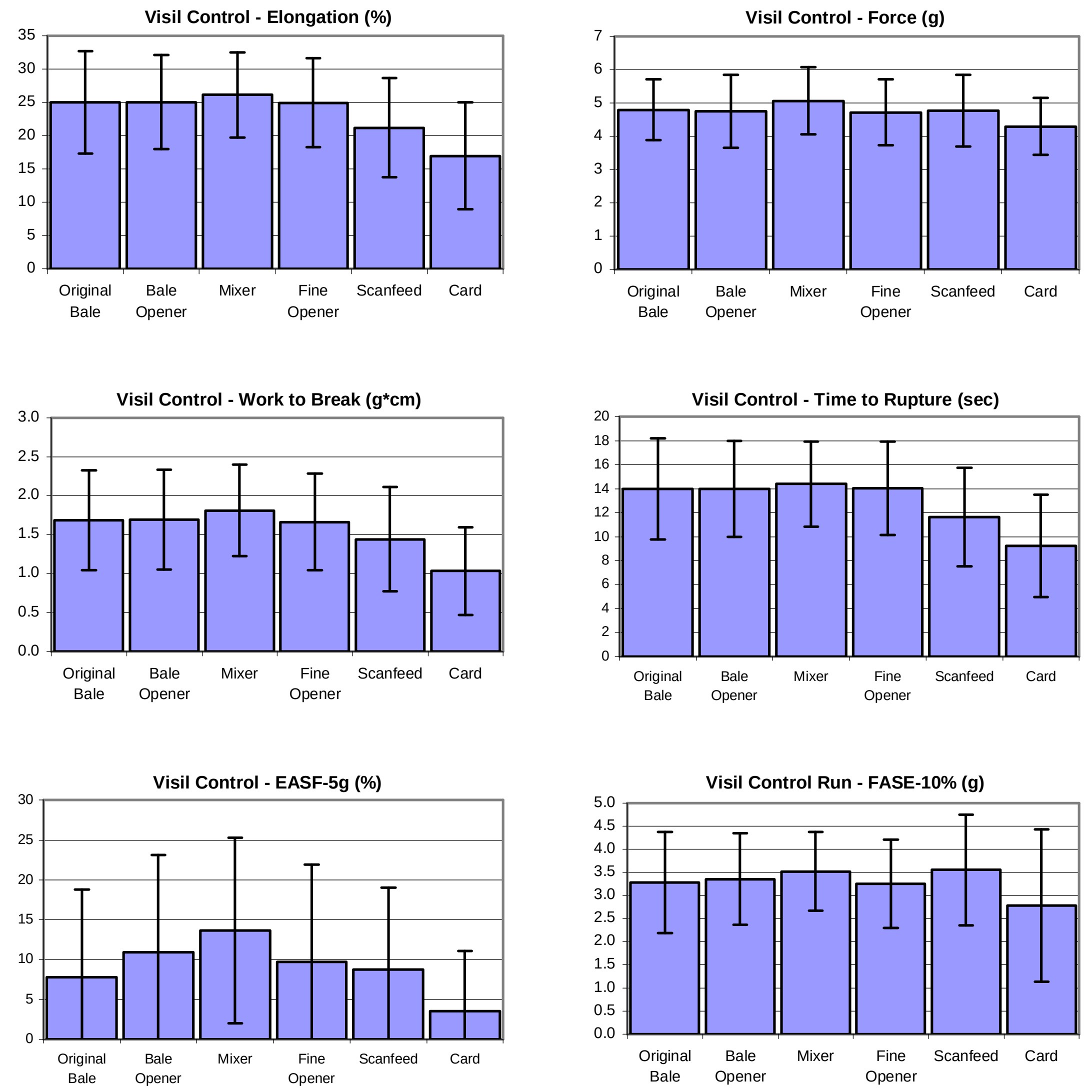


Figure 23: Mean Values for Fiber Properties Found to be Significantly Different

After the LSD procedure was performed and each machine's mean values were compared it was found that for elongation the scanfeed and the card had significantly different mean values than each other and the rest of the machines. This is also true for time to break. The card was also found to have a significantly different mean for the force values. For the Visil Control run work to break, it was found that the original bale, bale opener, fine opener and mixer all had similar mean value, but the scanfeed and card were significantly different. It was also found that the original bale, bale opener, fine opener and scanfeed could be grouped together with similar values and that the mixer and card were significantly different from this group. When looking at work to break, overall the card is significantly different from all other machines. For the EASF-5g values, again several machines could be grouped together with similar mean values. The first grouping was the bale opener, mixer and fine opener and the second group of similar values was the original bale, bale opener, fine opener and scanfeed. Again, the card was found to have a significantly different mean value than all other machines. Finally for the FASE-10% values all machines had similar means except for the card. All this can be seen and better understood in Table 14.

Table 14: Mean Values and Groupings for Significantly Different Fiber Properties

Visil Control - Elongation (%)				
Similar Means			Mean	Machine
A			25.01	Original Bale
A			25.04	Bale Opener
A			26.15	Mixer
A			24.96	Fine Opener
	B		21.22	Scanfeed
		C	16.97	Card

Visil Control - Force (g)			
Similar Means		Mean	Machine
A		4.79	Original Bale
A		4.75	Bale Opener
A		5.06	Mixer
A		4.71	Fine Opener
A		4.76	Scanfeed
	B	4.29	Card

Visil Control - Work to Break (g*cm)				
Similar Means			Mean	Machine
A	B		1.68	Original Bale
A	B		1.69	Bale Opener
A			1.81	Mixer
A	B		1.66	Fine Opener
	B		1.44	Scanfeed
		C	1.03	Card

Visil Control - Time to Rupture (sec)				
Similar Means			Mean	Machine
A			13.98	Original Bale
A			13.98	Bale Opener
A			14.40	Mixer
A			14.05	Fine Opener
	B		11.65	Scanfeed
		C	9.23	Card

Visil Control - EASF- 5g (%)				
Similar Means			Mean	Machine
	B		7.81	Original Bale
A	B		10.89	Bale Opener
A			13.63	Mixer
A	B		9.71	Fine Opener
	B		8.72	Scanfeed
		C	3.48	Card

Visil Control - FASE-10% (g)			
Similar Means		Mean	Machine
A		3.28	Original Bale
A		3.35	Bale Opener
A		3.52	Mixer
A		3.25	Fine Opener
A		3.55	Scanfeed
	B	2.78	Card

In Table 15 it can be seen that the mean values for the elongation, work to break, time to rupture and EASF-5g were found to be significantly different for the Visil fibers mixed for 45 minutes and then collected after each machine.

Table 15: Processing Machine Influence on Visil 45 Mix Fiber

VIS - 45 Mix	Bale	BO	Mix	FO	SF	Card	ANOVA			
	Mean	Mean	Mean	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	**25.01**	**25.04**	**26.57**	**24.78**	**21.84**	**16.35**	**13.58**	**<.0001**	**Significant**	**2.8106**
Force	4.79	4.75	4.76	4.66	4.81	4.39	1.21	0.3040	Insignificant	-
Tenacity	1.24	1.23	1.32	1.20	1.26	1.14	1.15	0.3352	Insignificant	-
Work	**1.68**	**1.69**	**1.76**	**1.59**	**1.54**	**1.06**	**8.36**	**<.0001**	**Significant**	**0.2462**
Time	**13.98**	**13.98**	**14.90**	**13.68**	**12.23**	**8.99**	**14.39**	**<.0001**	**Significant**	**1.562**
Denier	4.08	4.15	3.82	4.19	4.00	4.11	0.87	0.5014	Insignificant	-
EASF-5g	**7.81**	**10.89**	**11.77**	**10.10**	**9.79**	**4.26**	**2.91**	**0.0140**	**Significant**	**4.4351**
FASE-10%	3.28	3.35	3.23	3.32	3.53	3.14	0.61	0.6899	Insignificant	-

The four bar graphs in Figure 24 show the means for the fiber properties from the Visil 45Mix run found to have significantly different means.

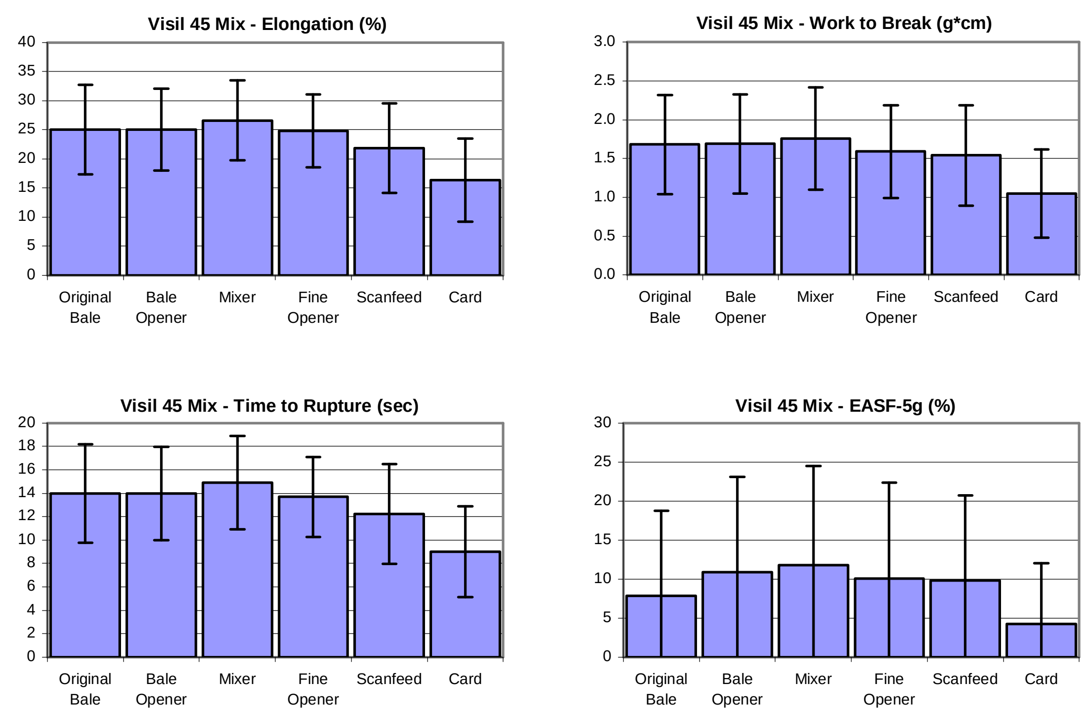


Figure 24: Mean Values for Fiber Properties Found to be Significantly Different

After performing the LSD procedure it was found that for the Visil 45 Mix elongation, the Scanfeed and the Card had significantly different means from the rest of the machines, and significantly different from each other. For work to break, the card was found to have a significantly different mean from the rest of the processing machines. For time to break the card was found to be significantly different from all other machines, while the fine opener and scanfeed were found to also be grouped together with similar means. For the EASF-5g value, the card was again found to be significantly different from all other machines except for the original bale. All of these findings are depicted in Table 16.

Table 16: Mean Values and Groupings for Significantly Different Fiber Properties

Visil 45 Mix - Elongation (%)				
Similar Means			Mean	Machine
A			25.01	Original Bale
A			25.04	Bale Opener
A			26.57	Mixer
A			24.78	Fine Opener
	B		21.84	Scanfeed
		C	16.35	Card

Visil 45 Mix - Work to Break (g*cm)			
Similar Means		Mean	Machine
A		1.68	Original Bale
A		1.69	Bale Opener
A		1.76	Mixer
A		1.59	Fine Opener
A		1.54	Scanfeed
	B	1.06	Card

Visil 45 Mix - Time to Break (sec)				
Similar Means			Mean	Machine
A			13.98	Original Bale
A			13.98	Bale Opener
A			14.90	Mixer
A	B		13.68	Fine Opener
	B		12.23	Scanfeed
		C	8.99	Card

Visil 45 Mix - EASF-5g (%)			
Similar Means		Mean	Machine
A	B	7.81	Original Bale
A		10.89	Bale Opener
A		11.77	Mixer
A		10.10	Fine Opener
A		9.79	Scanfeed
	B	4.26	Card

Table 17 reveals that the mean values for elongation, work to break and time to rupture from the Visil 90Mix run were found to be significantly different.

Table 17: Processing Machine Influence on Visil 90 Mix Fiber

VIS - 90 Mix	Bale	BO	Mix	FO	SF	Card	ANOVA			
	Mean	Mean	Mean	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	**23.83**	**25.04**	**27.24**	**26.24**	**23.83**	**15.97**	**18.05**	**<.0001**	**Significant**	**2.6548**
Force	4.79	4.75	4.93	4.82	4.97	4.51	1.39	0.2293	Insignificant	-
Tenacity	1.24	1.23	1.31	1.28	1.26	1.16	0.92	0.4710	Insignificant	-
Work	**1.68**	**1.69**	**1.81**	**1.71**	**1.67**	**1.10**	**8.51**	**<.0001**	**Significant**	**0.2419**
Time	**13.98**	**13.98**	**15.01**	**14.58**	**13.14**	**8.97**	**16.61**	**<.0001**	**Significant**	**1.5042**
Denier	4.08	4.15	4.00	4.03	4.22	4.10	0.3	0.9135	Insignificant	-
EASF-5g	7.81	10.89	10.80	9.73	9.85	5.76	1.58	0.1647	Insignificant	-
FASE-10%	3.28	3.35	3.32	3.34	3.61	3.17	0.81	0.5452	Insignificant	-

The bar graphs in Figure 25 depict the means for the fiber properties of the Visil 90Mix run that were found to be significantly different. By looking at the graphs it is easier to see the differences from machine to machine.

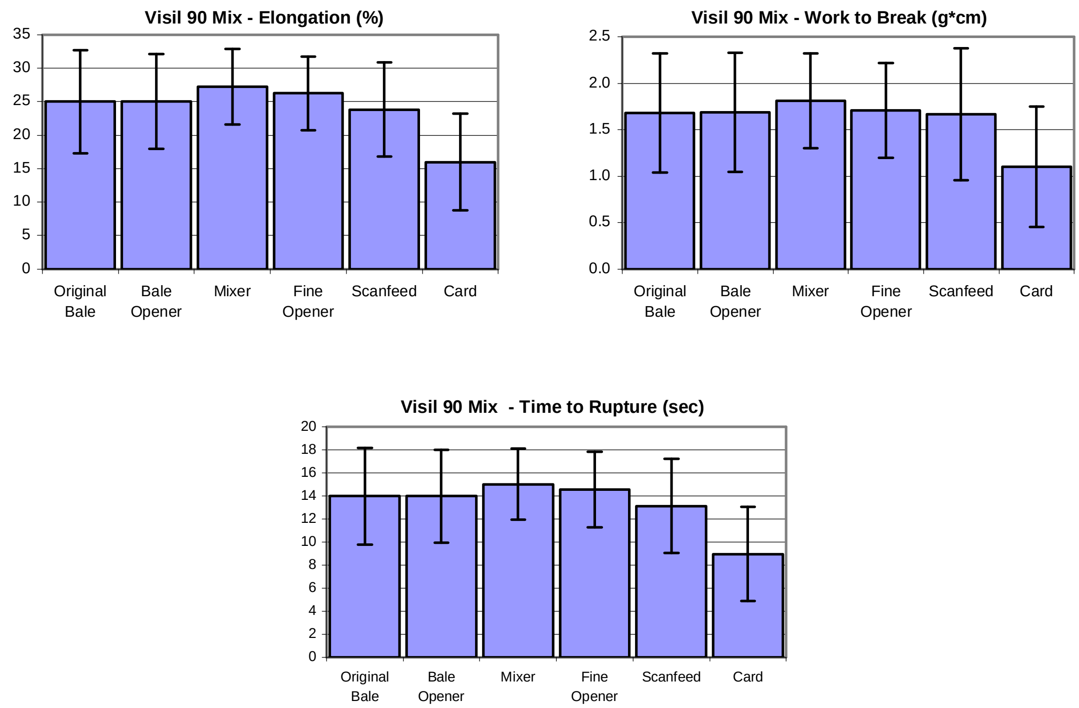


Figure 25: Mean Values for Fiber Properties Found to be Significantly Different

Table 18 depicts the mean values graphed in Figure 25 and shows the similar groupings based on the Fisher's LSD procedure. The values grouped together are significantly similar while those with different letters are significantly different from each other.

Table 18: Mean Values and Groupings for Significantly Different Fiber Properties

Visil 90 Mix - Elongation (%)				
Similar Means			Mean	Machine
A			25.01	Original Bale
A			25.04	Bale Opener
A			27.24	Mixer
A			26.24	Fine Opener
	B		26.83	Scanfeed
		C	15.97	Card

Visil 90 Mix - Work to Break (g*cm)			
Similar Means		Mean	Machine
A		1.68	Original Bale
A		1.69	Bale Opener
A		1.81	Mixer
A		1.71	Fine Opener
A		1.67	Scanfeed
	B	1.10	Card

Visil 90 Mix - Time to Rupture (sec)				
Similar Means			Mean	Machine
A	B		13.98	Original Bale
A	B		13.98	Bale Opener
A			15.01	Mixer
A	B		14.58	Fine Opener
	B		13.14	Scanfeed
		C	8.97	Card

From Table 18 it can be seen that the fibers processed by the card have significantly different elongation, work to break and time to rupture values. This indicates the damaging effect the card has on Visil fibers. It can also be seen that the Visil fibers coming out of the scanfeed have a significantly different elongation value than the rest of the processing machines.

4.1.2. Effect of Mixing Amount

The next set of tables examines the effect that the mixing amount had on the fiber properties. The results are broken up by fiber and by each machine so that just the mixing amount can be assessed.

4.1.2.1. PET Fiber

Table 19-22 show the mean values found for all PET fiber properties measured by the Favimat. The results are separated by machine and mixing amount so that the means from each mixing amount could be compared and the difference determined.

Table 19: Effect of Mixing Amount on PET Fiber from the Mixer

Mixer	Ctrl	45Mix	90Mix	ANOVA			
	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	46.91	43.28	46.00	1.04	0.3553	Insignificant	-
Force	5.81	5.69	5.63	0.98	0.3772	Insignificant	-
Tenacity	4.14	4.08	4.06	0.14	0.8671	Insignificant	-
Work	3.59	3.18	3.33	1.44	0.2406	Insignificant	-
Time	24.91	22.88	24.85	1.42	0.2445	Insignificant	-
Denier	1.46	1.46	1.44	0.04	0.9610	Insignificant	-
EASF-5g	25.26	21.94	25.83	1.35	0.2634	Insignificant	-
FASE-10%	**3.47**	**3.53**	**3.19**	**3.5**	**0.0326**	**Significant**	**0.2733**

Table 20: Effect of Mixing Amount on PET Fiber from the Fine Opener

Fine Opener	Ctrl	45Mix	90Mix	ANOVA			
	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	47.46	44.47	48.70	1.69	0.1880	Insignificant	-
Force	5.73	5.74	5.71	0.02	0.9785	Insignificant	-
Tenacity	4.09	3.88	3.93	0.67	0.5156	Insignificant	-
Work	3.52	3.35	3.60	0.67	0.5125	Insignificant	-
Time	25.20	23.62	25.91	1.63	0.1992	Insignificant	-
Denier	1.46	1.57	1.54	1.03	0.3608	Insignificant	-
EASF-5g	27.41	22.19	28.47	3.01	0.0523	Insignificant	-
FASE-10%	3.30	3.51	3.35	0.99	0.3732	Insignificant	-

Table 21: Effect of Mixing Amount on PET Fiber from the Scanfeed

SCANFEED	Ctrl	45Mix	90Mix	ANOVA			
	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	44.86	44.90	47.19	0.54	0.5852	Insifnificant	-
Force	5.68	5.74	5.67	0.16	0.8529	Insifnificant	-
Tenacity	4.08	4.11	3.91	0.77	0.4642	Insifnificant	-
Work	3.34	3.39	3.42	0.06	0.9377	Insifnificant	-
Time	24.46	23.69	25.17	0.55	0.5758	Insifnificant	-
Denier	1.44	1.45	1.53	0.98	0.3766	Insifnificant	-
EASF-5g	**23.19**	**24.48**	**31.30**	**5.55**	**0.0047**	**Significant**	**5.1664**
FASE-10%	3.31	3.49	3.23	1.22	0.2980	Insifnificant	-

Table 22: Effect of Mixing Amount on PET Fiber from the Card

CARD	Ctrl	45Mix	90Mix	ANOVA			
	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	41.16	41.31	40.93	0.01	0.9875	Insignificant	-
Force	5.54	5.59	5.58	0.1	0.9070	Insignificant	-
Tenacity	4.07	4.09	4.02	0.16	0.8549	Insignificant	-
Work	2.95	2.99	2.89	0.11	0.8936	Insignificant	-
Time	22.63	22.31	21.89	0.15	0.8592	Insignificant	-
Denier	1.39	1.40	1.43	0.22	0.8038	Insignificant	-
EASF-5g	22.11	22.21	23.01	0.06	0.9413	Insignificant	-
FASE-10%	3.29	3.29	3.30	0	0.9983	Insignificant	-

From these four tables, the only two sets of means found to be significantly different were the FASE-10% of the PET Fiber from the mixing machine and the EASF-5g of the PET fiber from the Scanfeed.

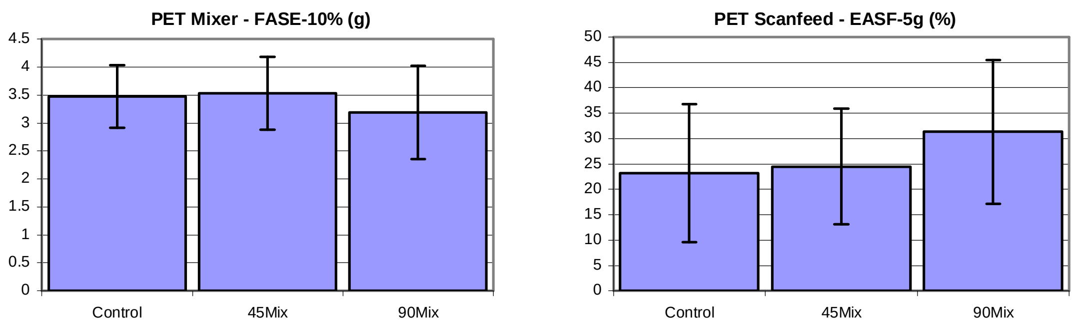


Figure 26: Mean Values for Fiber Properties Found to be Significantly Different

From the bar graphs in Figure 26, it appears as the 90-minute mixing amount produced significantly different values for the Mixer FASE-10% and the Scanfeed EASF-5g. To confirm this the LSD procedure was preformed.

Table 23: Mean Values and Groupings for Significantly Different Fiber Properties

PET Mixer - FASE-10% (g)			
Similar Means		Mean	Mix Amount
A		3.47	Control
A		3.53	45 Minutes
	B	3.19	90 Minutes

PET Scanfeed - EASF-5g (%)			
Similar Means		Mean	Mix Amount
A		23.19	Control
A		24.48	45 Minutes
	B	31.30	90 Minutes

Table 23 shows the results of the LSD procedure, which confirm that the 90-minute mixing amount did produce significantly different mean values for the Mixer FASE-10% and the Scanfeed EASF-5g.

4.1.2.2. Visil Fiber

Table 24-27 show the analysis results when investigating the effect the mixing amount has on Visil fibers collected from each machine.

Table 24: Effect of Mixing Amount on Visil Fiber from the Mixer

Mixer	Ctrl	45Mix	90Mix	ANOVA			
	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	26.15	26.57	27.24	0.37	0.6895	Insignificant	-
Force	5.06	4.93	4.76	1.29	0.2776	Insignificant	-
Tenacity	1.32	1.32	1.31	0.01	0.9870	Insignificant	-
Work	1.81	1.76	1.81	0.12	0.8851	Insignificant	-
Time	14.40	14.90	15.01	0.42	0.6606	Insignificant	-
Denier	4.05	4.00	3.82	0.75	0.4760	Insignificant	-
EASF-5g	13.63	11.77	10.80	0.68	0.5063	Insignificant	-
FASE-10%	3.52	3.23	3.32	1.56	0.2143	Insignificant	-

Table 25: Effect of Mixing Amount on Visil Fiber from the Fine Opener

Fine Opener	Ctrl	45Mix	90Mix	ANOVA			
	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	24.96	24.78	26.24	0.83	0.4366	Insignificant	-
Force	4.71	4.66	4.82	0.43	0.6500	Insignificant	-
Tenacity	1.20	1.20	1.28	0.72	0.4871	Insignificant	-
Work	1.66	1.59	1.71	0.51	0.6020	Insignificant	-
Time	14.05	13.68	14.58	0.81	0.4474	Insignificant	-
Denier	4.21	4.19	4.03	0.42	0.6574	Insignificant	-
EASF-5g	9.71	10.10	9.73	0.02	0.9835	Insignificant	-
FASE-10%	3.25	3.32	3.34	0.15	0.8646	Insignificant	-

Table 26: Effect of Mixing Amount on Visil Fiber from the Scanfeed

SCANFEED	Ctrl	45Mix	90Mix	ANOVA			
	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	21.22	21.84	23.83	1.69	0.1884	Insignificant	-
Force	4.76	4.81	4.97	0.48	0.6180	Insignificant	-
Tenacity	1.22	1.26	1.26	0.19	0.8249	Insignificant	-
Work	1.44	1.54	1.67	1.49	0.2284	Insignificant	-
Time	11.65	12.23	13.14	1.64	0.1966	Insignificant	-
Denier	4.17	4.00	4.22	0.64	0.5287	Insignificant	-
EASF-5g	8.72	9.79	9.85	0.18	0.8372	Insignificant	-
FASE-10%	3.55	3.53	3.61	0.06	0.9389	Insignificant	-

Table 27: Effect of Mixing Amount on Visil Fiber from the Card

CARD	Ctrl	45Mix	90Mix	ANOVA			
	Mean	Mean	Mean	F-Stat	P-Value	Difference	LSD
Elongation	16.97	16.35	15.97	0.23	0.7949	Insignificant	-
Force	4.29	4.39	4.51	0.62	0.5391	Insignificant	-
Tenacity	1.08	1.14	1.16	0.58	0.5635	Insignificant	-
Work	1.03	1.06	1.10	0.19	0.8267	Insignificant	-
Time	9.23	8.99	8.97	0.06	0.9387	Insignificant	-
Denier	4.31	4.11	4.10	0.52	0.5950	Insignificant	-
EASF-5g	3.48	4.26	5.76	1.07	0.3472	Insignificant	-
FASE-10%	2.78	3.14	3.17	0.8	0.4494	Insignificant	-

From these four tables we can see that the mixing amount was not found to have a significant influence on any of the fiber properties of the Visil fiber from any of the processing machines.

4.2 <u>Peyer FL101/AL101 Results</u>

The following results are those collected from the Peyer FL101/AL101, which measures the fiber length distribution of fiber bundles. Since the Peyer machine reports results in percentage of fibers in grouped fiber lengths, increasing by 0.125" the data could not be statistically analyzed with ANOVA. For this reason the mean fiber lengths were graphed to observe fiber breakage by machine and mixing amount. The results are separated by fiber type since the original fiber length of the two fibers differed.

4.2.1. Effect of Processing Machine

The effect of each processing machine on fiber length distribution was investigated by graphing the mean fiber length measured.

4.2.1.1. PET Fiber

Figure 27 depicts the mean fiber lengths measured by the Peyer machine for all PET fiber samples. The results are divided by mixing amount so that the effect of the each machine could be seen. The original PET fibers were specified as having a fiber length of 1.5 inches. It can be seen in Figure 27 that the mean fiber length for the fibers from the original bale was measured as 0.86 inches with a 46 percent variation. This is most likely because the Peyer machine does not take the crimp of the fiber into account. For this reason, the results from the Peyer machine will be used as a comparative analysis only.

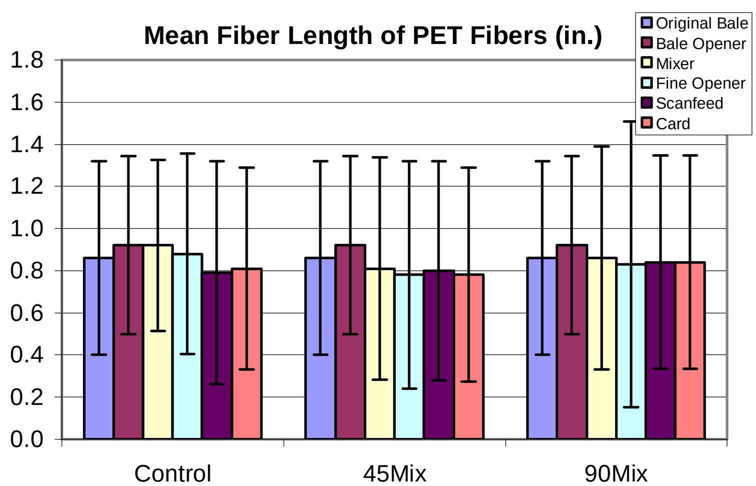


Figure 27: Effect of Processing Machine on PET Fiber Length

Looking at the results from Figure 27 it appears as though there was not much difference in the change of mean length between machines. The control run appeared to have a slight change after the fine opener but this change was not reflected in the 45mix and 90mix run. Bearing in mind the large variation, it appears as though the change in fiber length from machine to machine is not significant with the PET fibers.

4.2.1.2. Visil Fiber

The mean lengths of the Visil fibers measured in the Peyer machine are graphed in Figure 28. The results are separated by each run so that each machines influence can be observed. The length of the Visil fiber was specified as being 2 inches, but the Peyer machine reported the mean length of the fiber from the original bale as 0.92 inches with a variation of 61 percent. Again this is probably because the crimp of the fiber is not accounted for in the measurement.

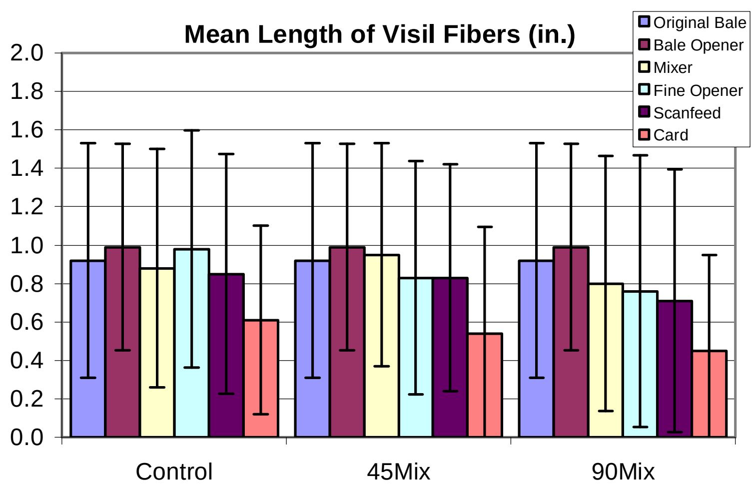


Figure 28: Effect of Processing Machine on Visil Fiber Length

Using the results in Figure 28 for comparative analysis a decline in fiber length can be seen for the Visil fibers. The mean fiber length progressively gets smaller from the mixer on. This indicates that there is a considerable amount of fiber breakage from the mixer, fine opener, scanfeed and card with the Visil fibers. From the bar graph it can also be seen that the card causes the most significant decline in mean fiber length.

4.2.2. Effect of Mixing Amount

The effect of the mixing amount on fiber length was also explored. The results were split up by fiber and processing machine so that the effect of mixing amount could be seen. Again the results were used as a comparative analysis since the fiber length measured was considerably different from the manufacturer's specified length for both fiber types.

4.2.2.1. PET Fiber

The first bar graph presented here shows the mean fiber length values for the PET fibers, measured by the Peyer machine. From looking at this graph in Figure 29 it appears as though the mixing amount did not have an effect on the mean length of the PET fibers.

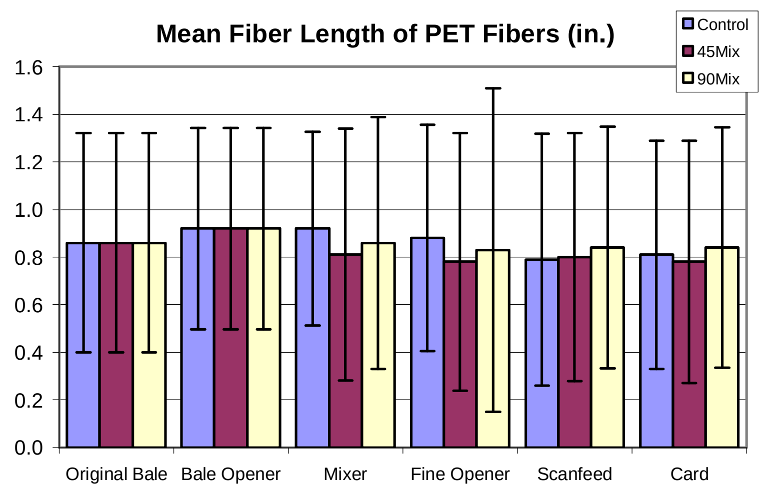


Figure 29: Effect of Mixing Amount on PET Fiber Length

4.2.2.2. Visil Fiber

The effect of the mixing amount on the mean length of Visil fibers was graphed in Figure 30. While the mixing amount did not have much effect on the PET fibers processed, this is not the case with the Visil fibers.

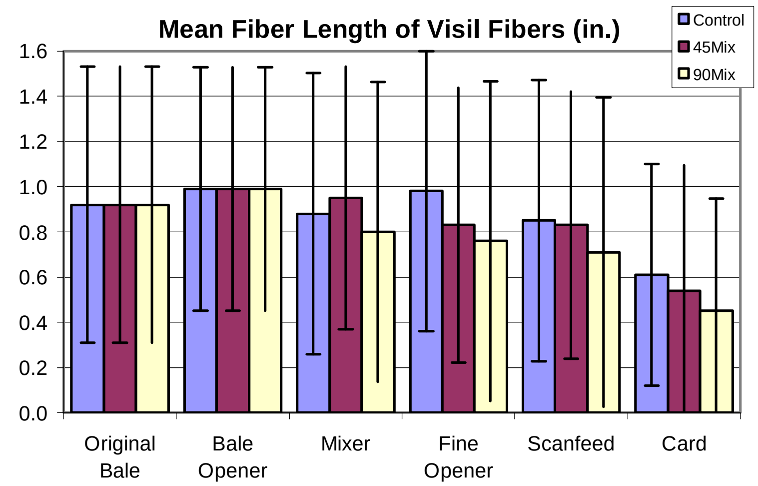


Figure 30: Effect of Mixing Amount on Visil Fiber Length

It appears that the mixing amount did have a considerable effect on the mean fiber length for the Visil fibers. The mean fiber length declines as the amount of time the fibers spent cycling in the mixer increases. For some reason this is not observed with the results from the mixer but a clear decline in fiber length is seen with fibers from the fine opener, scanfeed and card.

4.3 Uniformity Image Analysis Results

The uniformity image analysis results were reported according to a uniformity index where 100 represents perfect uniformity. Since each of the fabric samples were analyzed on four different size levels, 8x8", 4x4", 2x2" and 1x1", the mean and variation from these analyses are reported in each table. The ANOVA results comparing these means are also reported. Obviously uniformity will be influenced by basis weight, which varied with the web-forming system, but this was not included in the current discussion.

4.3.1. Influence of Mixing Amount

The first set of data presented from the uniformity analysis tests examines the influence of the mixing amount on web uniformity. The results reported are divided by fiber and processing machine so just the influence of mixing amount could be revealed.

4.3.1.1. PET Fiber

Table 28 and 29 examine the influence that the mixing amount had on PET webs produced. Table 28 compares the mean values of the scanfeed webs produced according to mix amount and Table 29 compares the mean values of the card/crosslapped webs produces.

Table 28: Influence of Mixing Amount on Uniformity of PET Scanfeed Webs

PET - SF	Control		45 Mix		90 Mix		ANOVA			
	Mean	CV%	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference	LSD
Image Analysis										
8x8	**42.63**	**17.43%**	**41.70**	**13.36%**	**46.30**	**17.54%**	**3.49**	**0.0347**	**Significant**	**3.6561**
4x4	**28.43**	**34.65%**	**30.91**	**32.03%**	**32.68**	**25.89%**	**6.15**	**0.0024**	**Significant**	**2.3939**
2x2	**19.53**	**53.30%**	**22.46**	**44.52%**	**22.93**	**46.84%**	**15.07**	**<.0001**	**Significant**	**1.3155**
1x1	**21.20**	**54.86%**	**21.80**	**50.46%**	**22.16**	**51.08%**	**3.57**	**0.0283**	**Significant**	**0.7161**

Table 29: Influence of Mixing Amount on Uniformity of PET Card/Crosslapped Webs

PET - CX	Control		45 Mix		90 Mix		ANOVA			
	Mean	CV%	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference	LSD
Image Analysis										
8x8	64	12.94%	65	9.19%	62	12.21%	1.24	0.2943	Insignifiant	-
4x4	**60**	**10.28%**	**62**	**9.69%**	**62**	**8.17%**	**4.34**	**0.0137**	**Significant**	**1.4676**
2x2	**54**	**11.59%**	**57**	**10.54%**	**56**	**10.33%**	**27.35**	**<.0001**	**Significant**	**0.7656**
1x1	**49**	**14.67%**	**51**	**13.42%**	**50**	**13.76%**	**41.99**	**<.0001**	**Significant**	**0.4414**

When looking at the mean values, keep in mind that the mass variation **within** the samples is being assessed. The CV is looking at the variation **between** the sample uniformity numbers. For these values it seems as though the mixing amount does have a significant influence on web uniformity. As can be seen from the tables the mixing amounts created significantly different uniformity means in every size image analysis except for the 8x8" PET Card/Crosslapped fabric analysis. To visually depict this, bar graphs were created.

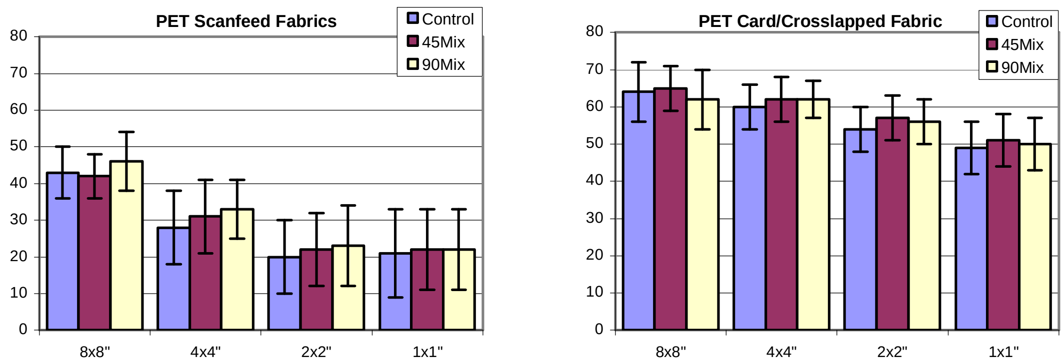


Figure 31: Effect of Mixing Amount on the Uniformity of PET Fabrics

From the graphs in Figure 31 not only can the effect of the mixing amount be seen, but the effect of the sample size analyzed can also be seen. As the sample size analyzed becomes smaller, the mean uniformity also decreases. The LSD procedure was performed to see exactly which mixing amounts differed. The results can be found in Table 30.

Table 30: Mean Values and Groupings for PET Fabrics by Mix Amount

PET Scanfeed 8x8"			
Similar Means		Mean	Mix Amount
A		42.63	Control
A		41.70	45 Minutes
	B	46.30	90 Minutes

PET Scanfeed 4x4"			
Similar Means		Mean	Mix Amount
A		28.43	Control
	B	30.91	45 Minutes
	B	32.68	90 Minutes

PET Scanfeed 2x2"			
Similar Means		Mean	Mix Amount
A		19.53	Control
	B	22.46	45 Minutes
	B	22.93	90 Minutes

PET Scanfeed 1x1"			
Similar Means		Mean	Mix Amount
A		21.20	Control
A	B	21.80	45 Minutes
	B	22.16	90 Minutes

PET Card/Crosslap 4x4"			
Similar Means		Mean	Mix Amount
	B	60.27	Control
A		62.45	45 Minutes
A	B	61.58	90 Minutes

PET Card/Crosslap 2x2"				
Similar Means			Mean	Mix Amount
A			54.37	Control
	B		57.21	45 Minutes
		C	56.24	90 Minutes

PET Card/Crosslap 1x1"				
Similar Means			Mean	Mix Amount
A			21.20	Control
	B		21.80	45 Minutes
		C	22.16	90 Minutes

4.3.1.2. Visil Fiber

The scanfeed and carded/crosslapped fabrics produced from the Visil fibers were also compared. In Table 31 it can be seen that with the Visil scanfeed webs the only uniformity mean values that were found to be significantly different were the 2x2" size samples. This is quite different then what was found with the PET fiber in the same scenario. Looking back at Table 28, the mix amount was found to have a significant affect on the uniformity of PET scanfeed fabrics but here we see in Table 31 that except for the 2x2" analysis the mix amount does not have a significant affect on the uniformity of Visil scanfeed fabrics.

Table 31: Influence of Mixing Amount on Uniformity of Visil Scanfeed Webs

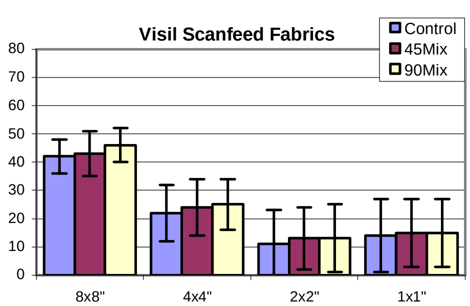
Visil - SF	Control		45 Mix		90 Mix		ANOVA			
	Mean	CV%	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference	LSD
Image Analysis										
8x8	42	13.61%	43	19.60%	46	12.34%	2.78	0.0674	Insignificant	-
4x4	22	45.02%	24	44.34%	25	37.13%	1.93	0.1471	Insignificant	-
2x2	**11**	**108.78%**	**13**	**90.34%**	**13**	**87.21%**	**7.07**	**0.0009**	**Significant**	**1.453**
1x1	14	86.75%	15	78.18%	15	83.89%	2.64	0.0717	Insignificant	-

When analyzing the influence of mixing amount on the uniformity of Visil Card/Crosslapped webs, Table 32 reveals that the mixing amount does have significant affect on web uniformity in all cases except for when the 8x8" image analysis is used. This is the same as the previously reported findings (Table 29) for the PET fiber.

Table 32: Influence of Mixing Amount on Uniformity of Visil Card/Crosslapped Webs

Visil - CX	Control		45 Mix		90 Mix		ANOVA			
	Mean	CV%	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference	LSD
Image Analysis										
8x8	64	9.71%	66	6.60%	67	6.55%	3.15	0.0477	Insignifiant	-
4x4	**55**	**9.44%**	**56**	**8.71%**	**58**	**9.73%**	**4.74**	**0.0093**	**Significant**	**1.3327**
2x2	**37**	**22.03%**	**37**	**20.40%**	**39**	**19.18%**	**9.75**	**<.0001**	**Significant**	**0.9783**
1x1	**23**	**44.73%**	**23**	**44.29%**	**26**	**39.16%**	**51.28**	**<.0001**	**Significant**	**0.649**

From the statistical analysis performed it can be concluded that the mixing amount does have a significant influence on carded/crosslapped fabrics from both fiber types but it seems as though when the fabric is produced with the scanfeed this is not the case. The mixing amount was found to have a significant influence on the PET scanfeed fabric uniformity, but an insignificant influence with the Visil Scanfeed fabric uniformity.



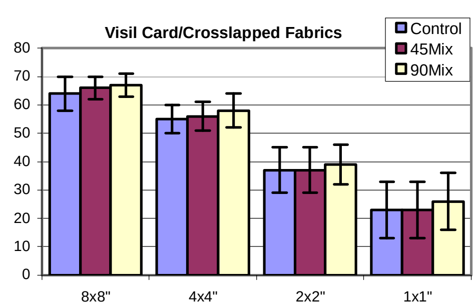


Figure 32: Effect of Mixing Amount on the Uniformity of Visil Fabrics

The bar graphs in Figure 32 are meant to show the effect of the three mixing amounts on the uniformity of the Visil fabrics produced. They also demonstrate the effect of the sample size on the uniformity number. To statistically see exactly which mixing amounts were significant, the LSD procedure was performed on the fabrics and samples sizes found to have significantly different means. The results can be found in Table 33.

Table 33: Mean Values and Groupings for Visil Fabrics by Mix Amount

Visil Scanfeed 2x2"			
Similar Means		Mean	Mix Amount
A		10.59	Control
	B	12.53	45 Minutes
	B	13.29	90 Minutes

Visil Card/Crosslap 4x4"			
Similar Means		Mean	Mix Amount
A		55.48	Control
A	B	56.27	45 Minutes
	B	57.55	90 Minutes

Visil Card/Crosslap 2x2"			
Similar Means		Mean	Mix Amount
A		37.04	Control
A		36.96	45 Minutes
	B	38.90	90 Minutes

Visil Card/Crosslap 1x1"			
Similar Means		Mean	Mix Amount
A		23.05	Control
A		23.19	45 Minutes
	B	26.02	90 Minutes

4.3.2. Influence of Web Forming Machines

The image analysis results were also used to compare the web forming machines. Again ANOVA was used to compare the mean uniformity numbers found for each size of sample analyzed and based on the p-value it was determined whether there was a significant difference between the web uniformity of the scanfeed fabric and the carded/crosslapped fabric.

4.3.2.1. PET Fiber

Table 34-36 show the mean uniformity numbers found for both the scanfeed and card/crosslapped fabrics produced from PET fiber. The tables are separated by the three different mixing amounts.

Table 34: Influence of Web Forming Machine on Uniformity of PET Control Fabric

PET Ctrl	SCANFEED		Card/Crosslap		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	**43**	**17.44%**	**64**	**12.94%**	**111.18**	**<.0001**	**Significant**
4x4	**28**	**34.66%**	**60**	**10.28%**	**898.34**	**<.0001**	**Significant**
2x2	**20**	**53.31%**	**54**	**11.58%**	**3,933.29**	**<.0001**	**Significant**
1x1	**21**	**54.88%**	**49**	**14.68%**	**7,904.65**	**<.0001**	**Significant**

Table 35: Influence of Web Forming Machine on Uniformity of PET 45 Mix Fabric

PET 45 Mix	SCANFEED		Card/Crosslap		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	**42**	**13.35%**	**65**	**9.19%**	**235.82**	**<.0001**	**Significant**
4x4	**31**	**32.03%**	**62**	**9.68%**	**887.17**	**<.0001**	**Significant**
2x2	**22**	**44.51%**	**57**	**10.53%**	**4,250.94**	**<.0001**	**Significant**
1x1	**22**	**50.43%**	**51**	**13.41%**	**9,747.48**	**<.0001**	**Significant**

Table 36: Influence of Web Forming Machine on Uniformity of PET 90 Mix Fabric

PET 90 Mix	SCANFEED		Card/Crosslap		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	**46**	**17.55%**	**62**	**12.21%**	**58.17**	**<.0001**	**Significant**
4x4	**33**	**25.90%**	**62**	**8.17%**	**1,034.52**	**<.0001**	**Significant**
2x2	**23**	**46.85%**	**56**	**10.33%**	**3,570.15**	**<.0001**	**Significant**
1x1	**22**	**51.08%**	**50**	**13.76%**	**8,591.99**	**<.0001**	**Significant**

It can be concluded from the analysis results revealed in all three tables that the web-forming machine had a significant effect on the uniformity of the fabrics. Another way to interpret this is that the uniformity of the PET webs produced by the scanfeed was significantly different from the uniformity of the PET webs produced by the traditional card/crosslapped method. This can also clearly be seen when examining the uniformity mean values in the tables. To visually depict this difference, bar graphs were created for each trial run comparing the scanfeed and card/crosslapped fabric uniformity, these can be found in Figure 33.

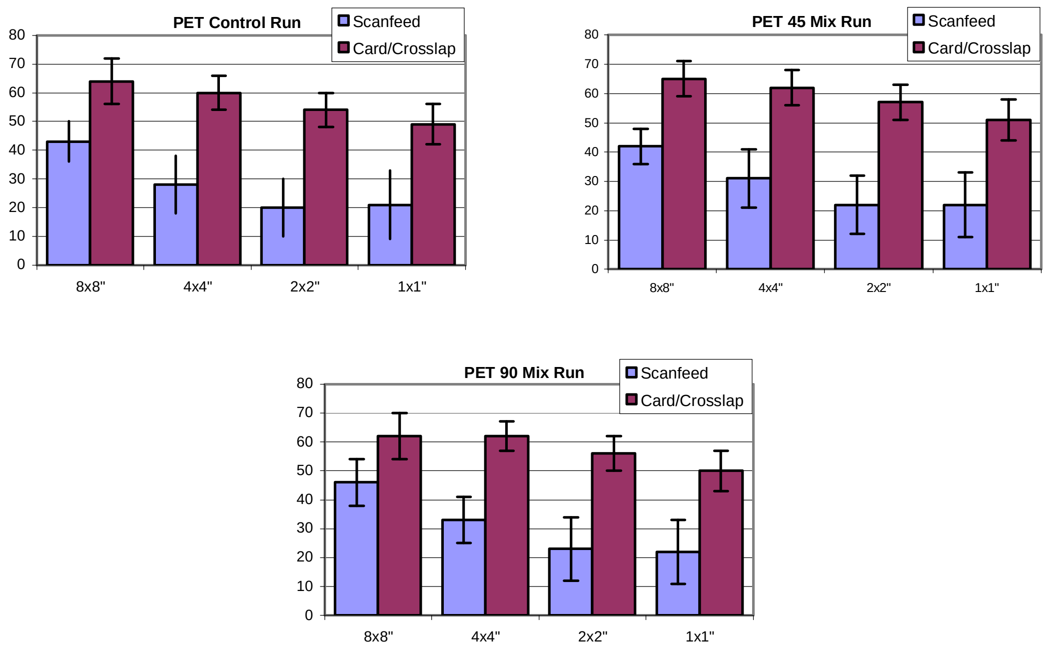


Figure 33: Comparing the Uniformity of Scanfeed and Card/Crosslapped PET Fabrics

From these graphs the difference in uniformity when comparing the PET scanfeed fabrics with the PET carded/crosslapped can clearly be seen. It can also be seen that as the sample size analyzed gets smaller, so does the mean uniformity value.

4.3.2.2. Visil Fiber

The fabrics produced by both web-forming machines with Visil fiber were also compared to assess the machines' influence on uniformity in respect to Visil fiber. Table 37-39 reveal the mean uniformity numbers found for all image analyses performed and the ANOVA results when comparing the machine means. The three tables are divided by the mixing amounts.

Table 37: Influence of Web Forming Machine on Uniformity of Visil Control Fabric

VIS Ctrl	SCANFEED		Card/Crosslap		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	**42**	**13.60%**	**64**	**9.70%**	**209.65**	**<.0001**	**Significant**
4x4	**22**	**45.02%**	**55**	**9.44%**	**1,034.01**	**<.0001**	**Significant**
2x2	**11**	**108.87%**	**37**	**22.02%**	**1,686.13**	**<.0001**	**Significant**
1x1	**14**	**86.74%**	**23**	**44.74%**	**531.71**	**<.0001**	**Significant**

Table 38: Influence of Web Forming Machine on Uniformity of Visil 45 Mix Fabric

VIS 45 Mix	SCANFEED		Card/Crosslap		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	**43**	**19.60%**	**66**	**6.61%**	**170.72**	**<.0001**	**Significant**
4x4	**24**	**44.32%**	**56**	**8.87%**	**949.48**	**<.0001**	**Significant**
2x2	**13**	**90.37%**	**37**	**20.41%**	**1,548.49**	**<.0001**	**Significant**
1x1	**15**	**78.16%**	**23**	**44.30%**	**464.85**	**<.0001**	**Significant**

Table 39: Influence of Web Forming Machine on Uniformity of Visil 90 Mix Fabric

VIS 90 Mix	SCANFEED		Card/Crosslap		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	**46**	**12.34%**	**67**	**6.56%**	**268.24**	**<.0001**	**Significant**
4x4	**25**	**37.11%**	**58**	**9.72%**	**1,112.28**	**<.0001**	**Significant**
2x2	**13**	**87.20%**	**39**	**19.18%**	**1,657.39**	**<.0001**	**Significant**
1x1	**15**	**83.87%**	**26**	**39.15%**	**927.53**	**<.0001**	**Significant**

From the ANOVA results, depicted in these three tables, it can be concluded that the web-forming machine does have a significant influence on the uniformity of the web produced, when using Visil fiber. These findings are similar to the previous findings on PET fiber. From this we can conclude that the uniformity of the Scanfeed fabrics produced is significantly different from the uniformity of the carded/crosslapped fabrics produced, regardless of fiber type. When actually observing the mean values we can see that not only are the uniformity numbers significantly different, the scanfeed fabrics consistently have a lower uniformity number than the carded/crosslapped fabrics.

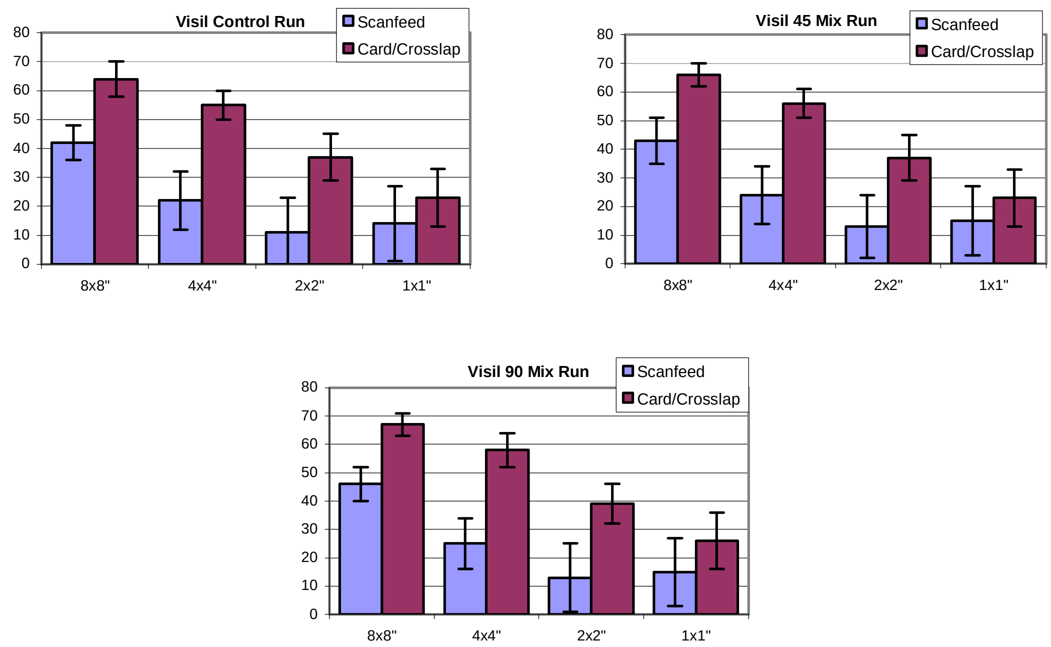


Figure 34: Comparing the Uniformity of Scanfeed and Card/Crosslapped Visil Fabrics

Again with the Visil fiber it is seen that the Scanfeed produces a significantly less uniform fabric than the traditional carded/crosslapped method. This is seen in every mix amount and sample size comparison.

4.3.3. Influence of Fiber Type

The influence of fiber type on web uniformity was also examined. The mean values of the uniformity numbers produced from the different size image samples were compared with ANOVA and the difference was determined to be significant or insignificant. The following tables are split up by the web-forming machine.

4.3.3.1. Scanfeed Fabric

Table 40-42 reveal the results of both the PET and Visil web uniformity numbers produced from the scanfeed fabrics. Table 40 compares the PET and Visil fabrics produced with the scanfeed machine, with straight through mixing. Table 41 compares the PET and Visil fabrics produced with the scanfeed machine, with 45 minute mixing. And Table 42 compares the PET and Visil fabrics produced with the scanfeed machine, with 90 minute mixing.

Table 40: Influence of Fiber Type on Uniformity of Scanfeed Control Fabric

SF Ctrl	PET		Visil		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	43	18.14%	42	13.60%	0.20	0.6555	Insignificant
4x4	**28**	**34.66%**	**22**	**45.02%**	**22.96**	**<.0001**	**Significant**
2x2	**20**	**53.31%**	**11**	**108.76%**	**159.35**	**<.0001**	**Significant**
1x1	**21**	**54.88%**	**14**	**86.74%**	**294.03**	**<.0001**	**Significant**

Table 41: Influence of Fiber Type on Uniformity of Scanfeed 45 Mix Fabric

SF 45 Mix	PET		Visil		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	42	13.35%	43	19.60%	0.81	0.3726	Insignificant
4x4	**31**	**32.03%**	**24**	**44.32%**	**30.09**	**<.0001**	**Significant**
2x2	**22**	**44.51%**	**13**	**90.37%**	**207.90**	**<.0001**	**Significant**
1x1	**22**	**50.43%**	**15**	**78.16%**	**296.08**	**<.0001**	**Significant**

Table 42: Influence of Fiber Type on Uniformity of Scanfeed 90 Mix Fabric

SF 90 Mix	PET		Visil		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	46	17.55%	46	12.34%	0.04	0.8401	Insignificant
4x4	**33**	**25.90%**	**25**	**37.11%**	**47.85**	**<.0001**	**Significant**
2x2	**23**	**46.85%**	**13**	**87.20%**	**178.61**	**<.0001**	**Significant**
1x1	**22**	**51.08%**	**15**	**83.87%**	**363.54**	**<.0001**	**Significant**

It can be seen from all three mixing amounts that the ANOVA analysis found when the sample image size being analyzed was 4x4", 2x2" or 1x1" the mean uniformity numbers were significantly different between fiber types. When looking at the uniformity numbers produced from 8x8" images the mean uniformity numbers between fiber types was not found to be significantly different.

4.3.3.2. Card/Crosslapped Fabric

Table 43-45 are looking at the same thing as the previous three tables, except they are comparing the PET and Visil fabrics produced with a card and crosslapper instead of the scanfeed machine. Again the tables are separated by the amount of mixing used to make the fabric being analyzed.

Table 43: Influence of Fiber Type on Uniformity of Card/Crosslapped Control Fabrics

CX Ctrl	PET		Visil		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	64	12.94%	64	9.70%	0.00	0.958	Insignificant
4x4	**60**	**10.28%**	**55**	**9.44%**	**41.75**	**<.0001**	**Significant**
2x2	**54**	**11.58%**	**37**	**22.02%**	**1,358.31**	**<.0001**	**Significant**
1x1	**49**	**14.68%**	**23**	**44.74%**	**8,146.00**	**<.0001**	**Significant**

Table 44: Influence of Fiber Type on Uniformity of Card/Crosslapped 45 Mix Fabrics

CX 45 Mix	PET		Visil		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	65	9.19%	66	6.61%	1.54	0.2203	Insignificant
4x4	**62**	**9.68%**	**56**	**8.71%**	**75.75**	**<.0001**	**Significant**
2x2	**57**	**10.53%**	**37**	**20.41%**	**2,111.54**	**<.0001**	**Significant**
1x1	**51**	**13.41%**	**23**	**44.30%**	**9,737.55**	**<.0001**	**Significant**

Table 45: Influence of Fiber Type on Uniformity of Card/Crosslapped 90 Mix Fabrics

CX 90 Mix	PET		Visil		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Image Analysis							
8x8	**62**	**12.21%**	**67**	**6.56%**	**14.76**	**0.0007**	**Significant**
4x4	**62**	**8.17%**	**58**	**9.72%**	**34.50**	**<.0001**	**Significant**
2x2	**56**	**10.32%**	**39**	**19.18%**	**1,612.89**	**<.0001**	**Significant**
1x1	**50**	**13.76%**	**26**	**39.15%**	**7,417.26**	**<.0001**	**Significant**

The image analysis findings analyzing the uniformity of the carded/crosslapped fabric are similar to the previous findings on scanfeed fabrics, when comparing the fiber type. With the exception of the 90 mix carded/crosslapped fabrics, all but the 8x8" mean values were found to be significantly different. For the 90 mix carded/crosslapped fabric the 8x8" uniformity mean numbers were also found to be significantly different when comparing the PET and Visil fabrics.

4.4 Basis Weight Uniformity Results

The mean basis weight of the 4x4" square samples weighed are revealed in the following tables. The ANOVA test was performed to determine whether the mixing amount and web-forming machine had an influence on the basis weight. The coefficient of variation of the samples' basis weights is also included in the tables. The variation is a critical value to look at when assessing the uniformity with basis weight. The CV indicates the weight fluctuations **between** the samples measured, whereas the image analysis results were reporting the uniformity **within** each sample.

4.4.1. Influence of Mixing Amount

The influence of the mixing amount on the basis weight, reported in grams per square meter, of the fabric is examined in Table 46 and 47. The ANOVA test was used to compare the mean weights of the samples collected from the Control, 45 mix and 90 mix trial runs. Table 46 shows the means and CVs for the fabrics produced from PET fiber while Table 47 shows the results of the fabrics made of Visil fiber.

Table 46: Influence of Mixing Amount on Basis Weight Uniformity of PET Fabrics

PET	Control		45 Mix		90 Mix		ANOVA			
	Mean	CV%	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference	LSD
Scanfeed	**255.26**	**7.32%**	**251.13**	**7.80%**	**247.69**	**6.57%**	**3.88**	**0.0218**	**Significant**	**5.3532**
Card/Cross	**157.74**	**10.37%**	**182.18**	**4.40%**	**176.28**	**4.03%**	**114.75**	**<.0001**	**Significant**	**3.314**

Table 47: Influence of Mixing Amount on Basis Weight Uniformity of Visil Fabrics

Visil	Control		45 Mix		90 Mix		ANOVA			
	Mean	CV%	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference	LSD
Scanfeed	**599.84**	**8.40%**	**592.34**	**8.54%**	**573.81**	**8.84%**	**6.33**	**0.0021**	**Significant**	**14.835**
Card/Cross	**193.67**	**5.27%**	**207.76**	**9.30%**	**220.77**	**8.45%**	**60.06**	**<.0001**	**Significant**	**4.8695**

As can be seen in Table 46 and Table 47 when comparing the mean basis weights the mixing amount was found to have a significant influence on the basis weight. It also appears that the mixing amount had a significant influence on the coefficient of variation with the carded/crosslapped fabrics. This is determined by comparing the CV values and noticing that with both the PET and Visil fiber the control run of the carded/crosslapped fabric appears to have a significantly different CV than both the 45mix and 90mix card/crosslapped fabric. The mean basis weights were graphed and can be found in Figure 35.

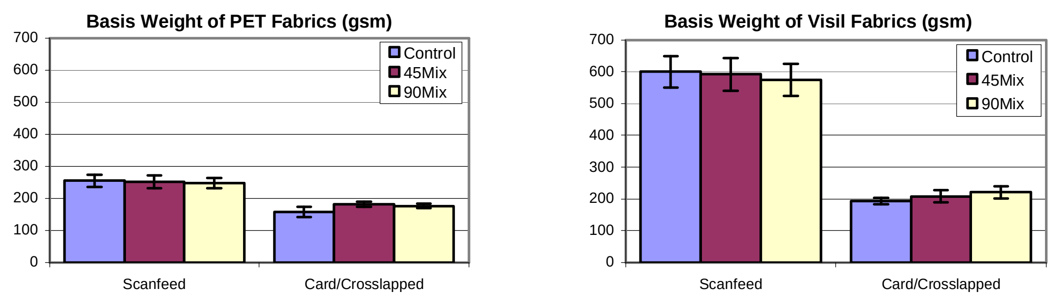


Figure 35: Mean Basis Weights of All Fabrics Produced

From these graphs it is easy to see that the scanfeed produces heavier fabrics than the carded/crosslapped fabrics. It can also be seen that the variation between the basis weights is higher with the scanfeed fabrics, when comparing them to the card/crosslapped fabrics. This trend is seen with both fiber types. It is a little harder to see the difference in mixing amounts from the bar graphs so the results from Fisher's LSD procedure, comparing the mixing amounts, can be found in Table 48.

Table 48: Mean Basis Weights and Groupings for All Fabrics Produced

PET Scanfeed Fabric			
Similar Means		Mean	Mix Amount
A		255.26	Control
A	B	251.13	45 Minutes
	B	247.69	90 Minutes

Visil Scanfeed Fabric			
Similar Means		Mean	Mix Amount
A		599.84	Control
A		592.34	45 Minutes
	B	573.81	90 Minutes

PET Card/Crosslap Fabric				
Similar Means			Mean	Mix Amount
A			157.74	Control
	B		182.18	45 Minutes
		C	176.28	90 Minutes

Visil Card/Crosslap Fabric				
Similar Means			Mean	Mix Amount
A			220.77	Control
	B		207.76	45 Minutes
		C	193.67	90 Minutes

One thing to note from the basis weight measurements is that the Visil scanfeed fabric was found to have a much higher basis weight than the PET scanfeed fabric. This can clearly be seen in Figure 35 and is an indication of the lack of fiber openness. Since the scanfeed distributes fiber amount based on volume instead of weight and the production parameters were the same for all trials, the production of heavier fabrics can help to indicate fiber openness. It appears as though the Visil fibers were not opened very well and therefore clumped together producing a much heavier scanfeed fabric than the adequately opened PET fibers.

4.4.2. Influence of Web Forming Machines

Influence of the web-forming machine on basis weight was also examined. Table 49 shows the mean basis weights and CVs of the PET fabrics produced and compares the Scanfeed fabrics to the carded/crosslapped fabrics.

Table 49: Influence of Web Forming Machine on Basis Weight of PET Fabrics

PET	SCANFEED		Card/Crosslap		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Control	**255.26**	**7.32%**	**157.74**	**10.37%**	**1,387.44**	**<.0001**	**Significant**
45 Mix	**251.13**	**7.80%**	**182.18**	**4.40%**	**954.80**	**<.0001**	**Significant**
90 Mix	**247.69**	**6.57%**	**176.28**	**4.04%**	**1,454.92**	**<.0001**	**Significant**

It can be seen from Table 49 that when comparing the scanfeed fabrics to the carded/crosslapped fabrics made from PET, the mean basis weight were found to be significantly different.

The next table, Table 50, shows the mean basis weights and CVs of the Visil fabrics produced. It also compares the scanfeed fabrics to the carded/crosslapped fabrics to see if the basis weights are significantly different.

Table 50: Influence of Web Forming Machine on Basis Weight of Visil Fabrics

Visil	SCANFEED		Card/Crosslap		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Control	**599.84**	**8.39%**	**193.67**	**5.27%**	**5,624.38**	**<.0001**	**Significant**
45 MIX	**592.34**	**8.54%**	**207.76**	**9.30%**	**4,541.23**	**<.0001**	**Significant**
90 MIX	**573.81**	**8.84%**	**220.77**	**8.45%**	**3,843.08**	**<.0001**	**Significant**

Like with the PET fabrics, the Visil fabrics' mean basis weights were found to be significantly different when comparing the web-forming machine. This is of no surprise since the difference can clearly be seen by just looking at the means. The coefficient of variation is much more interesting to look at in this case. It seems as though the scanfeed has a very consistent CV level, around 8% for Visil fabric but the carded/crosslapped CV values vary from 5-9%.

4.4.3. Influence of Fiber Type

The fabrics produced by different fiber types were compared just to see the influence fiber type had on basis weight uniformity. Table 51 contains the results for all the scanfeed fabrics while Table 52 has the results for all the carded/crosslapped fabrics.

Table 51: Influence of Fiber Type on Basis Weight of Scanfeed Fabrics

Scanfeed	PET		Visil		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Control	**255.26**	**7.32%**	**599.84**	**3.11%**	**3,704.50**	**<.0001**	**Significant**
45 Mix	**251.13**	**7.80%**	**599.84**	**8.39%**	**3,561.41**	**<.0001**	**Significant**
90 Mix	**247.69**	**6.57%**	**573.81**	**8.84%**	**3,375.41**	**<.0001**	**Significant**

Table 52: Influence of Fiber Type on Basis Weight of Card/Crosslapped Fabrics

Card/Cross	PET		Visil		ANOVA		
	Mean	CV%	Mean	CV%	F-Stat	P-Value	Difference
Control	**157.74**	**10.37%**	**193.67**	**5.27%**	**312.22**	**<.0001**	**Significant**
45 Mix	**182.18**	**4.46%**	**207.76**	**9.30%**	**134.63**	**<.0001**	**Significant**
90 Mix	**176.28**	**4.04%**	**220.77**	**8.45%**	**446.54**	**<.0001**	**Significant**

Both Table 51 and 52 indicate that the fiber type has a significant role on the basis weight of the fabrics produced. This was to be expected since there are so many property differences between the two different fibers.

5. CONCLUSIONS & FUTURE WORK

The preparatory processes prior to carding are crucial to producing quality dry-laid nonwovens with staple fibers. Proper opening, blending and if necessary cleaning is key to creating a uniformly blended and distributed web prior to bonding. Excessive processing can cause fiber damage and nep content decreasing the uniformity of the web and its overall quality. With this research, the influence of individual preparatory processing machines and their effect on fiber and web quality was assessed. Different fiber types, machine combinations and processing parameters were used.

A set of tests was used to assess the effect of each preparatory machine, the time the fiber spent in the mixer, and the uniformity of the web produced from a scanfeed machine versus a card and crosslapper. The influence of fiber type on web quality was also investigated. The set of tests included two tests to measure fiber properties and two tests that measured web uniformity. The results from these tests were reported in Chapter Four and have been compiled for summary and conclusions in this chapter.

Table 53 and Table 54 show the overall effect each processing machine had on the PET and Visil fibers processed. The tables are divided by machine and then further divided by mix amount so it can be seen exactly where the influence was observed. If the influence of the processing machine was found to be significantly different from all others, “SIG” was written in the corresponding box.

Table 53: Effect of Each Processing Machine on PET Fiber Properties

PET	Original Bale			Bale Opener			Mixer			Fine Opener			Scanfeed			Card		
	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix
Elongation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Force	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tenacity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Work	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time	-	-	SIG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	SIG
LinDen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EASF-5g	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FASE-10%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 54: Effect of Each Processing Machine on Visil Fiber Properties

Visil	Original Bale			Bale Opener			Mixer			Fine Opener			Scanfeed			Card		
	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix
Elongation	-	-	-	-	-	-	-	-	-	-	-	-	SIG	SIG	SIG	SIG	SIG	SIG
Force	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	SIG	-	-
Tenacity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Work	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	SIG	SIG	SIG
Time	-	-	-	-	-	-	-	-	-	-	SIG	-	SIG	SIG	-	SIG	SIG	SIG
LinDen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
EASF-5g	-	SIG	-	-	-	-	-	-	-	-	-	-	-	-	-	SIG	SIG	-
FASE-10%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	SIG	-	-

From these tables it is easy to see that the processing machines had a much stronger influence on the Visil fiber properties than the PET fiber properties. Examining Table 54 more closely reveals that, for most part, the fiber damage occurred with the scanfeed and carding machines. It can be concluded from this summary table that the card had the most influence on fiber properties. It can also be concluded that the fiber damage was observed in the elongation, work to break and time to rupture measurements.

To observe whether the mixing amount had an overall influence on the fiber properties the findings were compiled into summary tables divided by mixing amount and then processing machine. Table 55 reveals the influence the mixing amount had on PET fiber properties, while Table 56 shows the influence it had on Visil properties. Again when a significant different was observed, “SIG” was written in the box corresponding to where the observation was found.

Table 55: Effect of Mixing Amount on PET Fiber Properties

PET	Control				45 Minutes				90 Minutes			
	Mixer	FO	SF	Card	Mixer	FO	SF	Card	Mixer	FO	SF	Card
Elongation	-	-	-	-	-	-	-	-	-	-	-	-
Force	-	-	-	-	-	-	-	-	-	-	-	-
Tenacity	-	-	-	-	-	-	-	-	-	-	-	-
Work	-	-	-	-	-	-	-	-	-	-	-	-
Time	-	-	-	-	-	-	-	-	-	-	-	-
LinDen	-	-	-	-	-	-	-	-	-	-	-	-
EASF-5g	-	-	-	-	-	-	-	-	-	-	SIG	-
FASE-10%	-	-	-	-	-	-	-	-	SIG	-	-	-

Table 56: Effect of Mixing Amount on Visil Fiber Properties

VISIL	Control				45 Minutes				90 Minutes			
	Mixer	FO	SF	Card	Mixer	FO	SF	Card	Mixer	FO	SF	Card
Elongation	-	-	-	-	-	-	-	-	-	-	-	-
Force	-	-	-	-	-	-	-	-	-	-	-	-
Tenacity	-	-	-	-	-	-	-	-	-	-	-	-
Work	-	-	-	-	-	-	-	-	-	-	-	-
Time	-	-	-	-	-	-	-	-	-	-	-	-
LinDen	-	-	-	-	-	-	-	-	-	-	-	-
EASF-5g	-	-	-	-	-	-	-	-	-	-	-	-
FASE-10%	-	-	-	-	-	-	-	-	-	-	-	-

From the summary tables, Table 55 and Table 56, it can be seen that the mixing amount used in this experiment did not have a significant effect on fiber properties. There were only two significant differences observed and this was with the PET fibers at 90 minutes mixing. We can conclude from all Favimat findings that the processing machine had a much stronger influence on fiber properties than the amount of time spent cycling in the mixer.

Since the Peyer results were unable to be statistically analyzed the testing results were graphed and observable differences were noted. From these results it can be concluded that neither the processing machines nor the mixing amount had a clear effect on the fiber length of the PET. This was not the case with the Visil fibers. Both the processing machines and the mixing amount caused fiber breakage and a decline in fiber length was observed as the amount of processing increased.

A summary table was also created to observe all statistical results when comparing the mixing amounts influence on web uniformity. Table 57 reveals these results, separated by fiber type and web-forming machine so that the influence of only the mixing amount could be considered.

Table 57: Effect of Mixing Amount on Web Uniformity

Effect of Mix Amount	PET		Visil	
	SF	**CX**	**SF**	**CX**
Image Analysis				
8x8"	SIG	-	-	-
4x4"	SIG	SIG	-	SIG
2x2"	SIG	SIG	SIG	SIG
1x1"	SIG	SIG	-	SIG
Basis Weight				
gsm	SIG	SIG	SIG	SIG

Table 57 reveals significant differences found for all basis weight comparisons. There are somewhat mixed results when making comparisons with the image analysis data. With the PET fiber it was found that the fabrics with different mixing amounts also had significantly different uniformity numbers, indicating that the mixing amount did have an influence on uniformity (with the exception of the 8x8” carded/crosslapped fabric). When producing a nonwoven fabric from the Visil fiber with the scanfeed machine the results were quite different. The fabrics produced with different mixing amounts were not found to be significantly different, with the exception of the 2x2” fabric. But, when looking at the Visil carded/crosslapped fabric the same results are seen as with the PET. It is interesting to see such contrasting results when comparing the mixing amounts for the PET scanfeed fabrics versus the Visil Scanfeed fabrics. The weight of the fabric may have played a role in these results. The Visil Scanfeed fabric weighed significantly more than the rest of the fabrics, which could have affected these uniformity findings.

A summary table of the statistical analysis findings was compiled for the uniformity comparisons of the scanfeed fabrics with the carded/crosslapped fabrics. The results were separated by fiber and mix amount. Both the uniformity image analysis and basis weight results were included in Table 58.

Table 58: Effect of Web Forming Machine on Web Uniformity

SF vs. CX	PET			Visil		
	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix
Image Analysis						
8x8"	SIG	SIG	SIG	SIG	SIG	SIG
4x4"	SIG	SIG	SIG	SIG	SIG	SIG
2x2"	SIG	SIG	SIG	SIG	SIG	SIG
1x1"	SIG	SIG	SIG	SIG	SIG	SIG
Basis Weight						
gsm	SIG	SIG	SIG	SIG	SIG	SIG

Table 58 clearly indicates that there was a significant difference between the uniformity of the scanfeed fabrics produced and the carded/crosslapped fabrics. In all scenarios with both the image analysis and basis weight tests, significant differences were found. From this we can conclude that the uniformity of scanfeed fabrics produced from both fibers, with both mixing amounts, does not have uniformity comparable to a similar carded/crosslapped fabric. If the actual uniformity numbers were considered [Table 34-39] it is evident that in all cases the carded/crosslapped fabrics produced were more uniform than the scanfeed fabrics produced.

The next summary table, Table 59, compiles the statistical analysis findings when comparing the uniformity of the fabrics produced by fiber type. The comparisons were split up by web-forming machine and mix amount so that the influence of fiber type could be observed. Where a significant difference in uniformity was found between the PET and Visil fiber “SIG” was written in the corresponding box. The results from both the uniformity image analysis and the basis weight analysis were included.

Table 59: Effect of Fiber Type on Web Uniformity

PET vs. Visil	Scanfeed			Card/Crosslap		
	Ctrl	45Mix	90Mix	Ctrl	45Mix	90Mix
Image Analysis						
8x8"	-	-	-	-	-	SIG
4x4"	SIG	SIG	SIG	SIG	SIG	SIG
2x2"	SIG	SIG	SIG	SIG	SIG	SIG
1x1"	SIG	SIG	SIG	SIG	SIG	SIG
Basis Weight						
gsm	SIG	SIG	SIG	SIG	SIG	SIG

From Table 59, it can be concluded that, for the most part, the fiber types used in this experiment did have a significant influence on uniformity. A significant difference in uniformity was found in all fiber type comparisons except when 8x8" samples were analyzed with the image analysis program (with the exception of the card/crosslapped 90mix fabrics). It is interesting that this trend is observed. The fact that significant differences were not found in the 8x8" samples may indicate that the sample size analyzed was too large to detect changes in uniformity on a smaller level. In other words, while the average uniformity over the entire 8x8" samples may be similar, when comparing smaller sections of the same samples it was found that one of the samples was much less uniform and therefore found to be statistically different than the other.

The fact that the fiber types compared were found to have a significant influence on the uniformity of the fabrics produced is not surprising. The PET fiber is known to be a fairly easy fiber to process while the Visil fiber is difficult to process. Since the Visil fiber is difficult to process, more fiber damage and less opening occurs during preparatory processes. The fiber damage and breaking was observed in the fiber testing and the result of creating a web with damaged fibers is thus observed in the uniformity tests.

From the research it can be concluded that while the scanfeed machine does not damage the fibers as much as the carding machine, it also does not produce a web with comparable uniformity. It is suggested for future work that different machine combinations and parameters are explored to obtain more intense opening before the scanfeed. Since it was observed that the scanfeed does not open fibers as adequately as the card, there needs to be more intensive opening prior to this machine. It was also observed that the intense opening needed was not achieved by cycling fibers through the mixer for an extended period of time, so it is suggested to explore cycling the fibers through the fine opener more or to consider the use of a coarse opener. Currently the NCRC staple lab does not have this capability, but if the ductwork could be rearranged to make this possible, it would be interesting to see the outcome. The Visil fibers are very brittle and serve as a helpful fiber to use when measuring the effects of processing machines, so it would be suggested to use these fibers again.

It is suggested that further fiber and web testing methods should also be explored. Since the AFIS machine cannot be used to test man-made fibers, other testing instruments that measure fiber length and nep content should be searched out. A more accurate method for measuring fiber length should also be investigated, since the Peyer machine seems to either damage the fibers while measuring fiber length or to inaccurately measure them all together. The uniformity image analysis program used for this research seems very promising and further developing its capabilities is also suggested. It was very interesting to see how the measuring of fabric basis weight from the scanfeed machine could be used as a measurement of openness, due to the scanfeed's volumetric distribution system. As long as all machine and fiber parameters are kept constant a heavier fabric can indicate inadequate fiber opening. It is suggested that in future experiments assessing preparatory machinery that this be developed into a more in-depth testing method on its own.

REFERENCES

1. Aarnink, W.M.H. "AFIS Based, Quality Monitoring and Control in Textile Processing." MS Thesis, NCSU, 1996.

2. American Trutzshler. "Web Technology." Brochure obtained at TechTextil North American Trade Show in Atlanta, Georgia on March 29th, 2006.

3. Bauer-Kruz, Ina. "Fiber Crimp and Crimp Stability in Nonwoven Fabric Processes." PhD Dissertation, NCSU, 2000.

4. Chapman, L.M.R. "Effects of Needlepunch Density, Needle Penetration Depth, and Fiber Blend on Optimizing Needled Nonwoven Fabric Properties." MS Thesis, ITT, 1998.

5. Dahiya, A., Kamath, M, and Hedge, R. "Chemical Bonding." Updated April 2004. Retrieved from Website: http://www.engr.utk.edu/mse/pages/Textiles/Chemical%20Bonding.htm

6. Dahiya, A., Kamath, M, and Hedge, R. "Dry-Laid Nonwovens." Updated April 2004. Retrieved from Website: http://www.engr.utk.edu/mse/pages/Textiles/Dry%20Laid%20Nonwovens.htm

7. Dahiya, A., Kamath, M, and Hedge, R. "Spunlace (Hydroentanglement)." Updated April 2004. Retrieved from Website: http://www.engr.utk.edu/mse/pages/Textiles/Spunlace.htm

8. Dame S. Hamby Physical Testing Lab. "Peyer FL101/AL101." Retrieved from: http://www.tx.ncsu.edu/departments/texlabs/applied_research_labs/equipment_detail.cfm?id=645

9. Datla, Vasantha Madhuri. "The Influence of Fiber Properties and Processing Conditions on the Characteristics of Needled Fabrics." MS Thesis, NCSU, 2002.

10. DOA: Clever Nonwoven Technology. "Sheet Forming Plants." Brochure obtained at TechTextil North American Trade Show in Atlanta, Georgia on March 29th, 2006.

11. Doguc, Necmeddin Bener. "Influence of Fiber Types on Fiberweb Properties in High-Speed Carding." MS Thesis, NCSU, 2002.

12. ERKO-Trutzschler. "World of Nonwoven Technology." Brochure obtained at TechTextil North American Trade Show in Atlanta, Georgia on March 29th, 2006.

13. Hsu, Oscar K. Fruedenberg Nonwovens, Lowell, Massachusetts, USA. "Dry Laid Web Formation" Basics Course, INDA-TEC 96, International Nonwovens Conference, September 11-13, Hyatt Regency Crystal City, Crystal City, Virginia, USA. Section 1.0-1.8.

14. Hudson, P.B., Clapp, A.C. and Kness, D. "Joseph's Introductory Textile Science," 6th edition. United States: Harcourt Brace Jovanovich College Publishers.

15. Huntoon, R. (1990), "The Needlepunch Handbook." Cary, North Carolina: Association of the Nonwoven Fabrics Industry.

16. Hwang, Y.J. "Formation of Fiberweb From Staple Microfibers." MS Thesis, NCSU, 1998.

17. Ikiz, Yuksel. "Fiber Length Measurement by Image Processing." PhD Dissertation, NCSU, 2000.

18. INDA – Association of the Nonwoven Fabrics Industry, Worldwide Outlook for the Nonwoven Industry 2004-2009.

19. Klein, W. (1987), "A Practical Guide to Opening and Carding." Short-staple Spinning Series, Volume 2. The Textile Institute Manual of Textile Technology.

20. Klein, W. (1994), "Man-made Fibres and their Processing." Short-staple Spinning Series, Volume 6. The Textile Institute Manual of Textile Technology.

21. Klein, W. (1998), The Technology of Short-staple Spinning, Volume 1: 2nd Edition. The Textile Institute Manual of Textile Technology.

22. Lawrence, C. (2003), "Fundamental of Spun Yarn Technology." Boca Raton, Florida: CRC Press.

23. McCreight, D., R. Feil, J. Booterbaugh and E. Backe. (1997), "Short Staple Yarn Manufacturing." Durham, North Carolina: Carolina Academic Press.

24. Ommi S.p.A. Brochure obtained at TechTextil North American Trade Show in Atlanta, Georgia on March 29th, 2006.

25. Ott, R.L. and M. Longnecker. (2001), "An Introduction to Statistical Methods and Data Analysis," 5th Edition. Duxbury Press.

26. Pneumatic Conveyors. "Fibre Blending." Brochure obtained at TechTextil North American Trade Show in Atlanta, Georgia on March 29th, 2006.

27. Pneumatic Conveyors. "Nonwoven Blending." Brochure obtained at TechTextil North American Trade Show in Atlanta, Georgia on March 29th, 2006.

28. Pourdeyhimi, B. (Feb2004), "ITMA 2003: Technology – Nonwovens," Textile World, Retrieved from: http://www.textileworld.com/News.htm?CD=2284&ID=6610

29. Pourdeyhimi, Behham and Zamfir, Maria. "Staple Web Formation by Carding & Crosslapping." Nonwovens Cooperative Research Center. Presented in class on September 5, 2005.

30. Robert, K. and L. Blanchard. (1997), Cotton Cleanability Part I: Modeling Fiber Breakage. Textile Research Journal, Textile Research Institute, 67:6.

31. Sateri International Group. Fiber Producer's Homepage: http://www.sateri.com/web_en/product4.asp

32. Secretariat of the International Cotton Advisory Committee. "Survey of the Fiber Testing Equipment". Washington, DC: International Cotton Advisory Committee, Sept. 2006.

33. Smith, K. "The Effects of Fiber Length, Fiber Denier, Needlepunch Density, and Needle Penetration on the Physical Characteristics of As-Needled and Heat Treated Needlepunched Polypropylene Nonwoven Fabric." MS Thesis, ITT, 1992.

34. Smith, R. "The Effects of Fiber Properties and Web Uniformity on Nonwoven Polypropylene Needlepunch Fabrics." MS Thesis, ITT, 1998.

35. Temafa: Global Blending Solutions. Brochure obtained at TechTextil North American Trade Show in Atlanta, Georgia on March 29th, 2006.

36. Velmurugan, M. "The Role of Fiber Finish in the Conversion of Fiber to Nonwovens." MS Thesis, NCSU, 1999.

37. Wagner, J.R. "Effect of Variables in Textile Fibers Utilized in Carded Nonwovens." TANDEC Conference, 1996.

38. Wulfhort, B., Gries, T. and Veit, D. "Principles and Machinery for Yarn Production," ***Textile Technology***. Hanser Gardner, 2006.