To The Graduate Council

I am submitting herewith a thesis written by Xiao Gao entitled "Effects of Water Treatment on processing and Properties of Cotton/Cellulose Acetate Nonwovens " I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Textile Retailing and Consumer Sciences

Kermit E. Duckett

Kermit E Duckett, Major Professor

We have read this thesis
and recommend its acceptance

Mary Sue Younger

Accepted for the Council·

Associate Vice Chancellor and
Dean of The Graduate School

Effects of Water Treatment on Processing and Properties of Cotton/Cellulose Acetate Nonwovens

A Thesis Presented for the Master of Science Degree
The University of Tennessee, Knoxville

Xiao Gao
August, 2000

DEDICATION

This thesis is dedicated to my Grandparents,

Mr. Yunpeng Gao; Mrs. Shihui Nie

and my parents

Mr. BaoRui Gao; Mrs. Yingyin He

Who give me so much courage, support, endless love
and so many invaluable educational opportunities.

ACKNOWLEDGEMENTS

I am very glad to have had the opportunity to come to The University of Tennessee to study from People's Republic of China. Although there were some initial difficulties for me as a foreign student at first, many people offered me support and made my stay most enjoyable. The memories are precious.

I would like to particularly thank my major professor - Dr K E. Duckett for his support, kindness, and guidance. He was always very nice and patient with me, and gave me many valuable suggestions. During the one and one-half years of study, I learned not only technical knowledge, but also learned how to be a better person with a valuable perspective on life.

I would like to express appreciation for the great help from Dr. Gajannan Bhat, who gave me the chance to be involved in such an interesting and useful project. He is a very knowledgeable person and I have always enjoyed conversations with him Many precious ideas and considerable insight resulted.

I would like to thank Dr Duckett and Dr Bhat who are also thesis committee members again for their great help during my research I will never forget how they have helped me to run the thermal calendering machine in so many hot days, how they treated the students just like family members, how they have helped me to practice and present a research presentation.

I would like to thank Dr Mary Sue Younger for her valuable advice and guidance in the statistical analysis of the data In class, she was most knowledgeable and always made the class very vivid. Her great confidence, work-respect spirit and challenging attitude during her teaching provided most-satisfying experience.

I would like to deeply thank Ms Haoming Rong, my best friend for her great help during my study and life-especially for her help in processing the fabric and obtain testing information She is a precious girl who is always there and offers her hand whenever help is needed without any complain I am fortunate to have such a nice friend in my life

I would like to express my thanks to the technicians and graduate students in the department of Consumer and Industry Services Management for helping me run the processing machinery. I would like to show special thanks to Mr Richard Meade for his great help in nonwoven processing and his nice friendship.

I would like to thank my family, most of whom are in P R. China, for their great support through my study I would like to specially thank to my youngest aunt, Ms Ying Gao, who is also my idol since childhood, for her endless encouragement, love, and advice in my life.

Lastly, I would like to thank my dear husband, Mr. Yuanheng Zhang, for his inspiration, endless love and great help through my work.

ABSTRACT

Environmentally friendly nonwoven fabrics can be formed through thermal bonding of cotton and cellulose acetate fiber blends at reduced bonding temperature with the aid of a plasticizer. Water has been introduced as an external plasticizer to lower the softening temperature of cellulose acetate fibers and to enhance the tensile strength of cotton/cellulose acetate web It has been found that water can significantly increase the tensile strength of cotton/cellulose acetate thermally bonded webs at reasonable bonding temperature, and water can enhance the web bonding to essentially the same degree as acetone treatment does. The mechanisms of water effect have been discussed and the optimal processing conditions are proposed through this work.

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1 INTRODUCTION

More and more nonwovens are used in everday life, such as disposable diapers, famınine sanitary napkins and premoistened wipes, and high performance applications. Around 50% of nonwoven products are disposable products. Yet, most of these products can not be biodegraded and end up as solid waste because they contain large amounts of synthetic fibrous components.

It is urgent for consumers to be concerned about our living environment, to maintain a clean world for our offspring and to solve the solid waste problem. The environmental impact of disposable products is becoming a major concern throughout the world [1, 2] People are seeking ways to produce biodegradable textile products by using biodegradable fiber

Cotton becomes a major choice for the nonwoven industry because of its biodegradability, softness, absorbency, and breathability. However, cotton is a non-thermoplastic fiber Its bonding needs the addition of thermoplastic binder fiber for the fusion of the binder fibers with adjacent cotton fiber at relatively low temperature. Most cotton-based nonwoven products are processed with binder fibers using thermal calendering, which is a clean and an economical process

At the beginning of the cotton-based nonwoven research, synthetic fibers such as low melting polyester, polyester copolymer, polypropylene and polyethylene were used as binder fibers [3, 4, 5, 6] However, the synthetic binder fiber could not be biodegraded,

thereby contributing to environment pollution It has been important to find the proper biodegradable binder fiber

Research on cotton-based nonwovens has been carried out at The University of Tennessee since 1987 by applying different kinds of binder fibers through thermal calendering Cellulose Acetate (CA) fiber has been applied most successfully as the binder fiber since it is a thermoplastic, hydrophilic and a biodegradable fiber. Thus, the biodegradable fabric made of cotton/cellulose acetate nonwoven blend has been developed rather extensively.

However, the tensile strength of the nonwoven fabric made with Cotton/Cellulose Acetate nonwoven blend is quite low and has not been suitable for consumer applications when it is processed under the temperatures associated with cellulose acetate's softening temperature (180°C-205°C) Solvent treatment has been introduced in order to modify the softening temperature of cellulose acetate fiber and to lower the calendering temperature, while maintaining enhanced tensile properties.

Acetone, a good solvent for cellulose fiber, was considered a choice in the solvent pre-treatment. Duckett, Bhat and others at The University of Tennessee have done research to examine the effect of acetone vapor pre-treatment and of 20% acetone solution pre-treatment on the cotton/cellulose acetate thermally bonded fabric. The results showed that these solvent treatments can decrease the softening temperature of cellulose acetate fiber and produce comparatively stronger webs. However, from a practical standpoint, manufactures do not like to have a process involving the use of acetone since the acetone

evaporates easily, and is flammable and toxic. These detrimental factors may cause major problems in manufacturing and pollute the working environment. Also, consumers may not prefer to buy acetone treated products, which may, for example, contain toxic substances.

In our research, the desire was to decrease the softening temperature of cellulose acetate without the aid of acetone treatment by applying either one of the following two methods:

1 External Plasticizer. Water is used to replace acetone as the plasticizer in the solvent pretreatment. The water penetration will break the intermolecular bonds and enhance the mobility of the polymer chains in cellulose acetate fiber so that the softening temperature is decreased.

2 Internal Plasticizer· Chemical or process modification is useed in the manufacture of cellulose acetate fiber with, perhaps, plasticizing agents which provide additional flexibility in thermal bonding by lowering the bonding temperatures and enhancing bonding adhesion.

The objective of our study was.

1 To examine how the plasticizing by water treatment affects the fabric tensile properties

2 To compare the effect of two binder fibers - ordinary cellulose acetate fiber and plasticized cellulose acetate fiber

3 To find the optimal processing conditions using statistical analysis

2 LITERATURE REVIEW

2.1 Nonwoven Definition

Almost fifty years of continuous development and progress have passed since the beginning of nonwoven industry production around 1942 [7]

Nonwoven fabrics are flat, porous sheets that are made directly from separate fibers or from molten plastics or from plastic film. Nonwoven fabrics are broadly defined as manufactured sheet, batting, webbing, or fabric that is held together by various methods, e.g , thermal fusion, resin and solvent bonding, or mechanical interlocking of fibers. The fibers in these structures may be directionally or randomly oriented, depending on the nature of their production process [8] The definitions of nonwovens most commonly used nowadays are those of the Association of Nonwoven fabrics Industry (INDA) and the European Disposables and Nonwovens Association (EDANA):

INDA Definition:

Nonwoven fabric is a sheet of natural or synthetic, organic or inorganic, fibers or filaments, which have not been converted to yarns, and are bonded to each other, not predominantly by hydrogen bonding but by any combination of the following means: adding an adhesive, thermally fusing the fibers or filaments to each other to other meltable fibers or powders; fusing the fibers to be bonded by first dissolving and then resolidifying their surfaces, creating physical tangles or tufts among the fibers; holding

the fibers or filaments in place with sewing or knitting stitches with yarn made from the fibers of the sheet or from other fibers [9].

EDANA Definition:

Nonwoven is a manufactured sheet, web or batt of directionally or randomly oriented fibers, bonded by friction, and/or cohesion and/or adhesion, excluding paper or products which are woven, knitted, tufted stitchbonded incorporating binding yarns or filaments, or felted by wetmilling, whether or not additionally needled. The fibers may be of natural or man-made origin. They may be staple or continuous or be formed in situ [9]. The production of nonwovens amounts to approximately 20% of the total production of textiles

Fibers, binders, and a bonding process are needed to manufacture a nonwoven. The steps in the processing of manufacturing nonwovens are shown in Figure 1.

Nonwoven fabrics demonstrate specific characteristics such as absorbency, liquid repellency, resilience, stretch, softness, strength, flame retardancy, washability, cushioning, filtering, bacterial barrier and sterility [10] They are used in a wide variety of applications such as disposable diapers, sanitary items, hospital gowns, wiping cloths; computer diskette linings, base materials for coated fabrics; interlinings; and engineering fabrics Some of the important applications are listed in Table 1 [11].

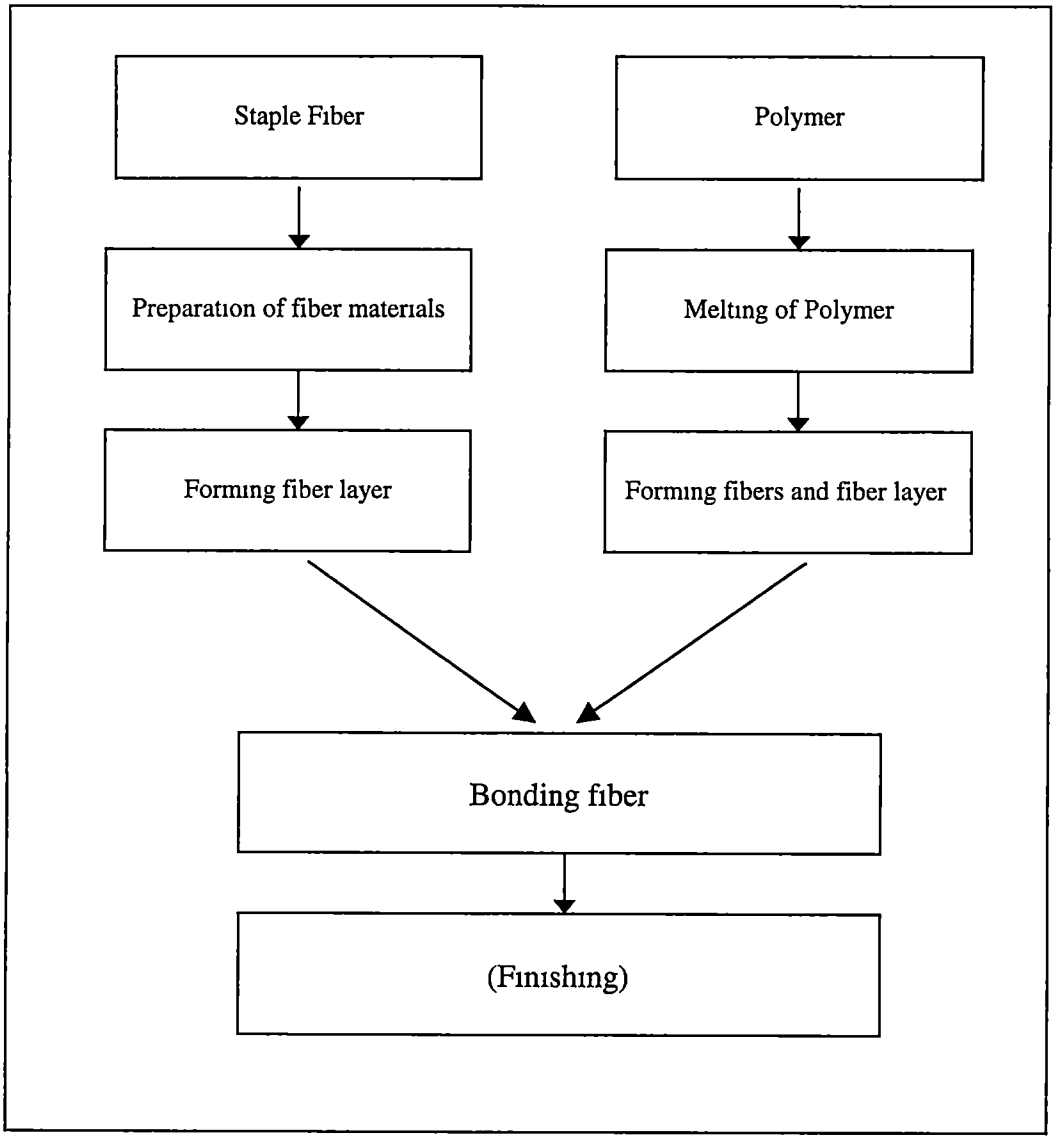


Figure 1 The Process of Manufacturing Nonwovens

Table 1 Some Examples of Nonwoven Products Usage

NONWOVEN USAGE	EXAMPLE
Agriculture and Landscaping	Crop Cover, Root Bags, Containers, Weed Control fabrics, Turf Protection Products
Automotive	Floor Covers, Side Liners, Transmission Oil Filters, Door Trim Panel Padding
Clothing	Interlinings, Bra and Shoulder Padding, Handbag Components, Clothing and Glove Insulation
Construction	House Wrap, Pipe Wrap, Insulation, Acoustical Ceiling, Roofing and Underlayment
Geotextiles	Drainage, Asphalt Overlay, Road and Railroad Beds, Pond Liners, Artificial Turf
Homefurnishings	Furniture Construction Sheeting, Quilt Backing, Dust covers, Flanging, Pillows, Blanket, Quilt Backing, Carpet Backing
Healthcare	Surgical Caps, Gowns, Masks, Shoe Covers Sponges, Dressings, Wipes, Dental Bibs
Household	Wipes, Scouring Pads, Dust Cloths, Mops, Tea and Coffee Bags, Napkins, Ironing Board Pads, Tablecloths, Washcloths
Industry/Military	Coated fabrics, Filters, Abrasives, Packaging
Leisure & Travel	Sleeping Bags, Tents, Artificial Leather, Luggage, Pillow Cases, Airline Headrests
Personal Care and Hygiene	Diapers, Sanitary napkins, Tampons, Training Pants, Dry and Wet Wipes, Cosmetic Applicators, Vacuum Cleaner Bags
School & Office	Bookcovers, Labels, Mailing Envelopes, Towels, Floppy Disk Liners

2.2 Raw Materials for Nonwovens

Fibers, polymer and binders are three important raw materials for producing nonwovens The raw materials are selected according to the desired properties of the final products and the processing method.

2.2.1 Fibers

Fiber is a unit of matter, either natural or manufactured, that forms the basic element fabrics and other textile structures A fiber is characterized by having a length at least 1000 times its diameter or width Typically, textile fibers are units that can be spun into a yarn or made into a fabric by various methods including weaving, knitting, braiding, felting, and twisting. While the term fiber is often referenced to staple, it also includes continuous filament and tow [8]

Fibers are the building block of all nonwovens, the fibers used in the production of nonwovens can be classified into two main groups. natural and man-made fibers

Natural Fibers

The natural fibers are those, such as cotton, wool, and silk, which are provided by nature in ready-made fibrous form. They are most frequently classified by origin as:

- Cellulosic Fibers: Cotton, Flax, Sisal
- Protein Fibers: Wool, Silk

- Mineral Fiber· Asbestos

Man-made Fibers

With nonwovens products successfully moving into more technical end-uses, the fiber requirements have also become more exacting with regard to the fiber properties More and more man-made fibers are produced to fulfill the industry need They are produced from fiber-forming substances, which may include

- Polymers synthesized from chemical compounds, e.g., acrylic, nylon, polyester, polyethylene, polyurethane, and polypropylene fibers
- Modified or transformed natural polymers, e.g., alginic and cellulose based fibers such as acetates and rayons
- Minerals, e g., glasses

Manmade fibers are the major raw materials for the products made by [12]:

- Fiber-to-web processes, typically produced by chemical processing of natural materials and solution spinning into fiber
- Melt spinning of synthetic polymers into fiber form
- Conversion of natural materials, such as glass, into fiber form

Although a large number of fibers are available, the dominant fibers are polyolefins, polyester, and rayon. These three fiber types make up a huge part of the overall nonwovens markets for fibers

Prior to1995, polyester was the most widely used polymer in the nonwovens industry. The next most popular was polypropylene [13], but polyolefin and particularly polypropylene moved ahead of polyester fibers in 1996. They had 46% market shares in fibers used for nonwovens, whereas, polyester had a 45% share. By the end of 1998, olefin fibers increased their share to 49% and polyester dropped to 42% [14]

2.2.2 Polymers

A polymer is a high macromolecular weight, chain-like structure from which manufactured fibers are derived by linking together molecular units called monomer [8] The overall chemical composition of a polymer and its distribution of molecular weights are major factors affecting its structure and properties.

The effects of temperature and added solvents on polymer conformational rearrangements, as related to the segmental mobility of various groups and chain consequences in polymer, are important for understanding the structure-property relationships and for characterization [15, 16]. Recent studies of polymer include the modification and/or combination of existing polymers, to tailor their properties for end uses

2.2.3 Binders:

Binder is an adhesive applied with a solvent, or being a thermoplastic melted or thermally softened condition to bond fiber together in a web or to bind one web to another [8].

There are several forms of binders used in nonwoven product [10]:

- Polymer solutions
- Polymer dispersions (latex)
- Foamed polymer dispersions
- Polymer pastes
- Solid polymers
- Thermoplastic fibers
- Thermoplastic powder
- Foils, nettings, or threads

Thermoplastic binders are a relatively new entry in the marketplace. They are generally classified as unicomponent and bicomponent fibers. The most common binders with their melting temperature are shown in Table 2 [11].

Table 2 The Most Commonly Used Binders

Polymer	T_m (°C)	Forms
Polypropylene	155-162	Fibers, bi-component fibers
Polyethylene	110-126	Powder, fiber, bi-component fiber
Co-Polyesters	110-256	Fibers, Powder bi-component fibers
Co-polyamides	110-190	Fibers, Powder bi-component fibers, spun-bonds

Nonwoven fabric engineers have a variety of binder types to choose from in their designing work The cost and desired nonwoven properties determine the selection of a binder

2.3 Web Forming Methods

All nonwoven fabrics are based on a fibrous web The physical properties of the final product are determined by the characteristics of the web, which depend largely on the web geometry and are influenced by the fiber diameter, fiber length, web weight, and chemical and mechanical properties of the polymer. Hence, it is very important to select the proper web forming method. The choice of methods for forming webs is largely determined by fiber length Newer methods have also been developed, such as webs formed from long filament directly from bulk polymers. Here, both fibers and webs are produced at the same time

In the following part, several main web-forming methods are introduced More specifically, the carding process is described in detail.

2.3.1 Dry-laid

The dry-laid process uses the conventional staple length fibers (12-200mm or longer, but not continuous) is based on the classical textile carding process of mechanically separating and orientating fiber. This usually refers to the fabrics formed from carded webs. The dry-laid process is shown in Figure 2. There are four phases of the dry-laid manufacturing system.

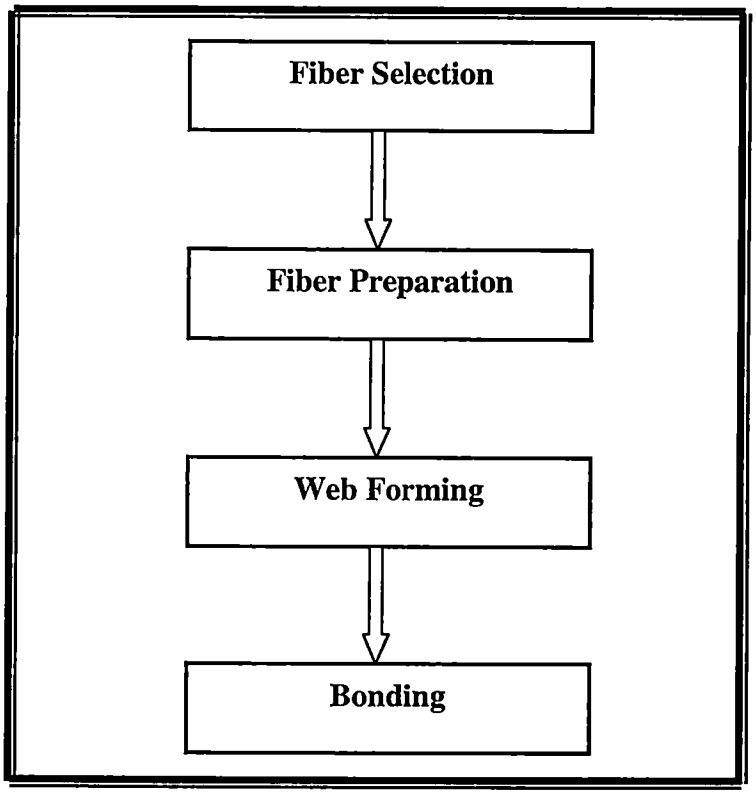


Figure 2 Flow Diagram of Dry Laid Process

Fiber Selection

In the selection of fibers for dry-laid nonwovens, several factors that need to be considered including· a) absorbency, b) abrasion resistance, c) bursting strength, d) permeability, e) softness and f) tear resistance in the fabric [17].

Fiber Preparation

Staple fibers are shipped to the manufacturer in the form of bales, and fiber preparation consists of three steps a) bale opening, b) blending, c) web-former feeding

Web Formation and Layering

There are three different web-forming methods

a) Mechanical Web Formation (Carding or Garnetting)

- Carding

  Carding is a basic process in the production of nonwoven webs. The construction of a carding machine and the working step are shown in Figure 3 [18] and Figure 4 [11]

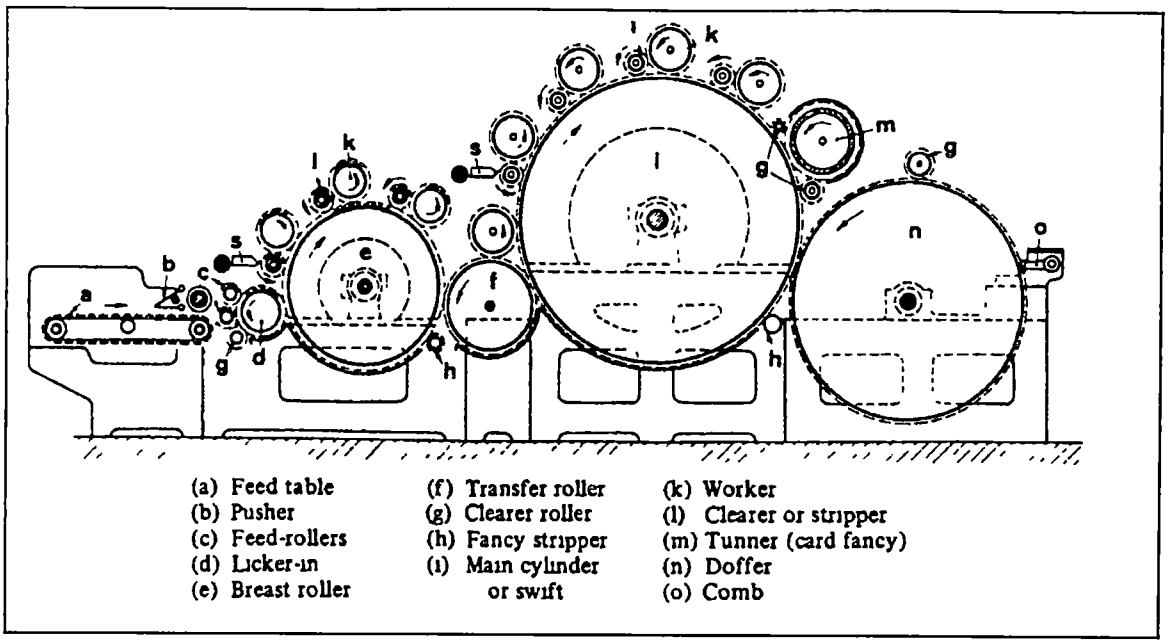


Figure 3 Construction of Carding Machine

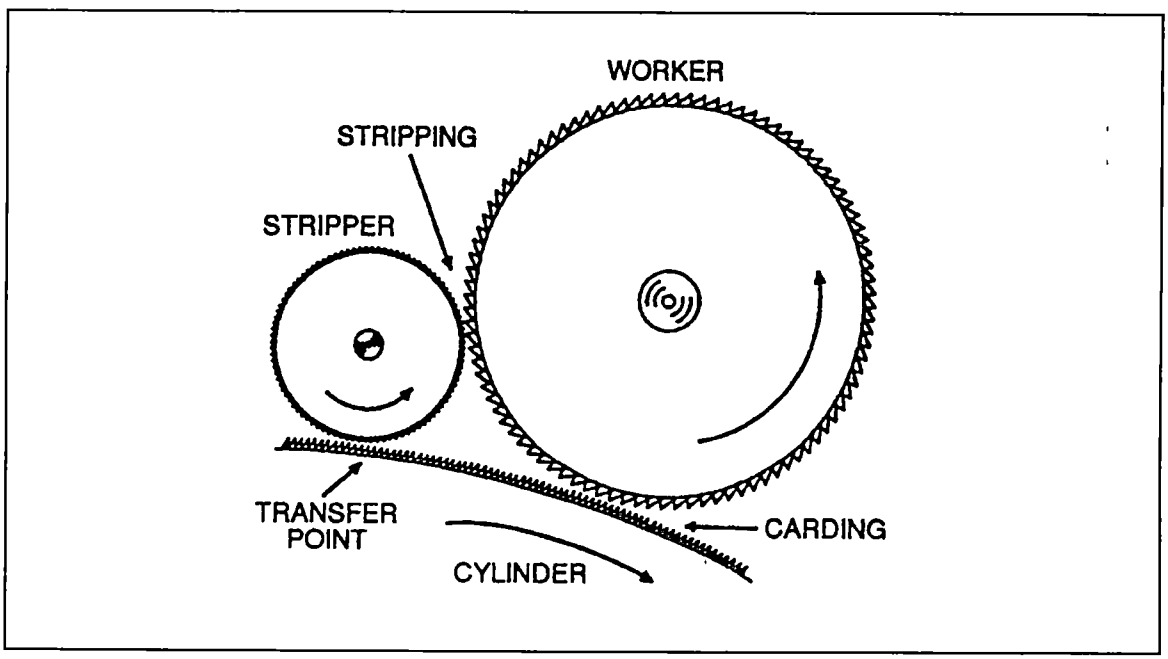


Figure 4 Working Steps of Carding Machine

It involves opening, removing waste, and blending thoroughly different species and lengths of fibers [11, 18, 19]. That shorter fibers are picked up with smaller probability than the longer ones, and affects the blend ratios somewhat. While processing a blend of two different fiber types, the two are treated independently by the card workers; that is, the movement of one component was not affected by the presence of the other [19].

The principle of carding is the mechanical action in which the fibers are held by one surface while the other surface combs the fibers, causing individual fiber separation. At the center of carding machine is a large rotating metallic cylinder covered with card clothing which is comprised of needles, wires, or fine metallic teeth embedded in a heavy cloth or in a metallic foundation The cylinder is partly surrounded by an endless belt of a large number of narrow, cast iron flats positioned along the top of the cylinder

The fibers are fed by a chute or hopper and condensed into the form of a lap or batting. This is initially opened into small tufts by a licker-in, which feeds the fibers to the cylinder The needles of the two opposing surfaces of the cylinder and flats or rollers are inclined in opposite directions and move at different speeds. The main cylinder moves faster than the flats and, due to the opposing needles and difference in surface speeds, the fiber clumps are pulled and teased apart. 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 [17].

The web is doffed from the surface of the main cylinder by a doffer roller and deposited on a moving belt. The orientation ratio of the web at the doffer of a conventional card is approximately 5:1

Productivity of older roller cards is about 30-50 kg/hour at the width of 1.5~2 m. Currently, roller cards having width 2~3 5 m have a processing performance up to 1000 kg/hour. Flat carding machines are usually 1 m wide and process about 5~50 kg/hour [11].

Spinning preparation and carding of staple fibers have been and still are the subjects of studies and publications concerning various aspects. There is even research on the carding of micro-fibers [20]. One shortcoming of the carding process is that the carded web always has area irregularities of mass distribution caused by machine variables, fiber properties and area irregularities of the fed fiber matt [19].

- Garnett

Garnetts are similar to roller-top cards R L Street has described the garnett as "a group of rolls placed in an order that allows a given wire configuration, along with certain speed relationships, to level, transport, comb and interlock fibers to a degree that a web is formed" [21]. Garnetts

deliver more random web than does the card. Most webs from garnetts are layered by crosslapping to build up the desired finished nonwoven weight.

b) Aerodynamic Web Formation (Air-Lay)

The orientation created by carding is effectively improved by capturing fibers on a screen from an air stream This is done on a Rando-Webber component. Starting with a lap or plied card web fed by a feed roller, the fibers are separated by a licker-in or spiked roller and introduced into an air stream.

c) Centrifugal Dynamic Web Formation (Random Card)

The centrifugal dynamic random card system forms a web by throwing off fibers from the cylinder onto a doffer with fiber inertia, which is subject to centrifugal force, in proportion to the square of the rotary speed. Orientation in the web is three-dimensional and is random or isotropic.

Web formations can be made into the desired web structure by the layering of the webs from either the card or garnett. Layering can be accomplished in several ways to reach the desired weight and web structure· a) longitudinal layering, b) cross layering (most common), c) perpendicular layering.

2.3.2 Wet Laid

Wet-laid nonwovens are nonwovens made by a modified papermaking process First, the fibers (less than 25 mm) are suspended in water Then, specialized paper machines are

used to separate the water from the fibers to form a uniform sheet of material, which is then bonded and dried. [22].

In 1996, 12.3% of the patents of all nonwoven processes were connected to the wet-laid process. It ranked third although more than one-half of the nonwoven process patents issued have been on extrusion systems - melt blown and spunbonded technologies [23]

There are three characteristic stages in the manufacture of nonwoven bonded fabrics by the wet-laid method [18]:

- Swelling and dispersion of the fiber in water, transport of the suspension on a continuous travelling screen
- Continuous web formation on the screen as a result of filtration
- Drying and bonding of the web

The wet-laid process has advantages of high productivity, control of orientation of properties, and high uniformity at low basis weight.

2.3.3 Melt-Blown

Melt blown is a process for producing fibrous webs or articles directly from polymers or resins using high-velocity air or another appropriate force to attenuate the filaments. The differences between melt-blown nonwoven fabrics and other nonwoven fabrics can generally be interpreted as differences in filament size, such as degree of softness, cover

or opacity, and porosity [24] The melt-blown process is unique because it can produce microfibers.

2.3.4 Spunbond

Spunbond fabrics are produced by the various steps in processing - polymer melting, filament extrusion, filament drawing, filament deposition, and bonding [11] Furthermore, air jets or electrostatic charges are used to separate the fibers during the web laying process Then the air stream passes through a perforated collecting surface so that the fibers are not deflected. Bonding imparts strength and integrity to the web by applying heated rolls or hot needles to partially melt the polymer and fuse the fibers together

Spunbond products are employed in carpet backing, geotextiles, and disposable medical/hygiene products. The process is generally more economical than those using staple fiber to make nonwoven fabrics [25, 26]. Spunbonded fabrics have a property combination falling between paper and woven fabric Spunbonded webs offer a wide range of product characteristics ranging from very light and flexible structures to heavy and stiff structure [27]

2.4 Web Bonding Methods

There are three major web bonding methods - mechanical bonding, chemical bonding, and hydroentanglement Sometimes, in order to achieve products with certain properties, the designers use the combination of different bonding methods.

2 4.1 Mechanical bonding:

- Needle punch

Needle punching is a process of bonding nonwoven web structures by mechanically interlocking the fibers through the web. Barbed needles, mounted on a board, punch fibers into the web leaving the fibers entangled. The needles are spaced in a non-aligned arrangement and are designed to release the fiber as the needle board is withdrawn. The product formed is extensible, bulky, conformable, distortable and extremely absorbent.

- Stitch bonding

Stitch bonding is the process of bonding a web by using stitching yarns, filaments, fibers, or just the stitching needles themselves to do the bonding. In many applications stitch-bonded fabrics take the place of woven goods because they are faster to produce and, hence, the cost of production is considerably reduced.

- Thermal bonding

Thermal bonding is the process of using heat to bond or stabilize a web structure that consists of a thermoplastic fiber. All or part of the fibers act as thermal binder, thus eliminating the use of latex or resin binders. Thermal bonding is the leading method used by the coverstock industry

for baby diapers Polypropylene has been the most suitable fiber with its low melting point of approximately 165° C It is also soft to touch. The fiber web is passed between heated calender rollers, where the web is bonded In most cases point bonding using embossed rolls is the most desired method, adding softness and flexibility to the fabric. Use of smooth rolls bonds the entire surface of the fabric increasing the strength, but reducing drape and softness

2.4.2 Chemical bonding

Bonding a web by means of a chemical is one of the most common methods of bonding. The chemical binder is applied to the web and is cured. The most commonly used binder is latex, because it is economical, easy to apply and very effective. Several methods are used to apply the binder and these include saturation bonding, spray bonding, print bonding and foam bonding

2.4.3 Hydroentanglement

Hydroentanglement is a process of entangling individual fibers with each other by using water jets with varying degrees of water pressure The higher the water pressure, the greater is the degree of entanglement. Entanglement occurs when the water strikes the web and the fibers are deflected The vigorous agitation within the web causes the fibers to become entangled. It is more like an anchor point than a rigid bond point

and the fabric made tends--as do some needlepunched fabrics--to have low elastic recovery

2.4.4 Bonding Combinations

There are so many types of web bonding methods and all of them are very important to nonwoven designers. They can be used singly or in combination to manufacture a multitude of aesthetically pleasing and functional nonwovens for a competitive market place [28].

2.5 Properties of Cotton Fiber

Cotton is a cellulose ($C_6H_{10}O_5$) based fiber, it is molecularly comprised of chains of the cellulose unit whose structure is shown in Figure 5 [29].

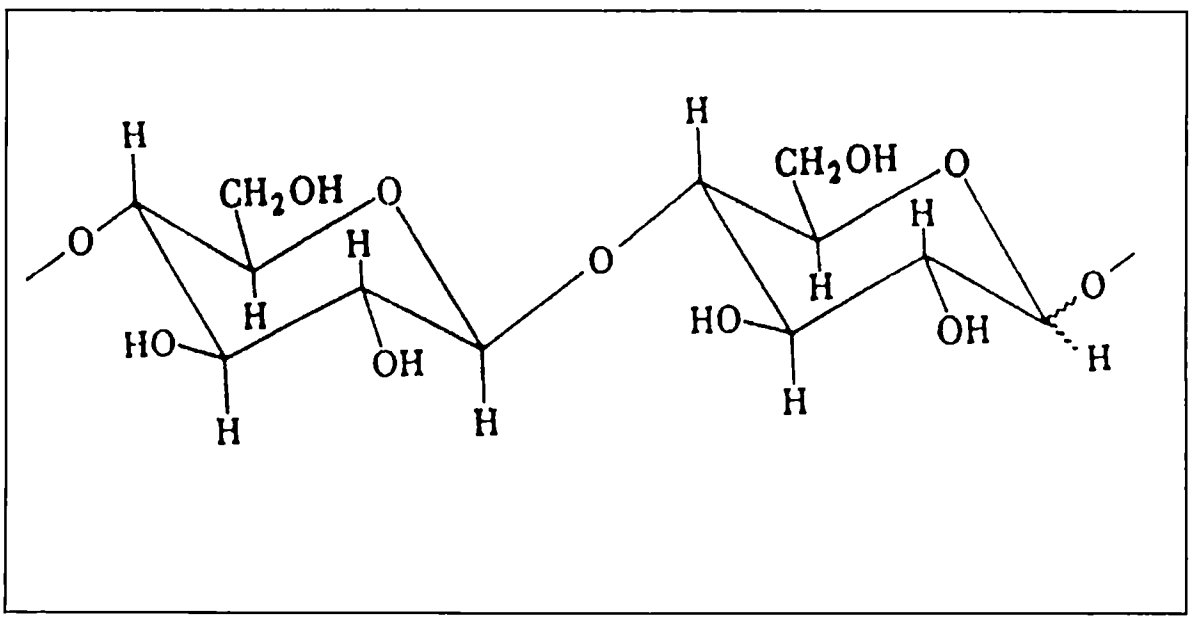


Figure 5 The Structure of Cellulose

Raw cotton consists of approximately 96% cellulose and 4% of waxes, pectin, and other proteinaceous and plant material These minor constituents can be removed by scouring and bleaching processes to give the soft, clean, white, absorbent fiber that is satisfactory for the nonwoven industry The fiber has excellent absorbency and feels comfortable against skin. It has good strength both wet and dry, and has moderate dimensional stability and elastic recovery [30].

Cotton fiber is a strong fiber with a tenacity of 3.0-5 0 g/denier or 0.19-0 45 N/tex. The elongation of cotton fiber can be 5-10 % It has 8.5 % moisture regain. The decomposition temperature of cotton is in the range of 150-240 °C.

The earliest evidence of using cotton as a textile fiber is from India and the date assigned to this fabric is around 3000 B.C. There have been discoveries of cotton fabrics of comparable age in Southern America. Cotton cultivation first spread from India to Egypt, China and the South Pacific Even though cotton fiber had been known already in Southern America, the large-scale cotton cultivation in Northern America began in the 16th century with the arrival of colonists to southern parts of today's United States [31].

The largest rise in cotton production is connected with the invention of the saw-tooth cotton gin by Eli Whitney in 1793 [32]. With this new technology, it was possible to produce more cotton fiber, which resulted in big changes in the spinning and weaving industry, especially in England.

Cotton today is the most used textile fiber in the world It is used throughout the world in a very broad range of textile materials because of its versatility and comfort It is often

blended with other staple fibers - especially polyester - to take advantage of the characteristics of both fibers. World textile fiber consumption in 1998 was approximately 45 million tons. Of this total, cotton represented approximately 20 million tons [33] Its current market share is 56 percent for all fibers used for apparel and home furnishings sold in the U.S. [34]. It is generally recognized that most consumers prefer cotton personal care items to those containing synthetic fibers [35].

Cotton nonwovens can be recycled, re-used or disposed off by natural degradation conditions Cotton is a readily renewable resource with long-term supply assurance Extensive research is continuously improving bleached fiber quality and quantity. Cotton's share of the textile fiber market has been steadily increasing and will continue to increase, as the consumers prefer cotton-containing items.

2.6 Properties of Cellulose Acetate Fiber

The melting temperature of ordinary cellulose acetate is around 232 °C with a softening temperature in the range of 190-205 °C Cellulose Acetate (CA) fiber has low crystallinity and orientation because of the irregular chain structure with acetyl and hydroxyl groups and the weak intermolecular forces [36]. It has a tenacity of 1.1-1.3 g/denier and falls to 0 65-0.75 g/denier when it is wet. The elongation of cellulose acetate fiber can be 20-30 % and increases to 35-45 % when it is wet CA fiber is soft and supple with low modulus and high extensibility. The specific gravity of cellulose acetate is about 1 30. It has 6 5 % moisture regain and will swell 6-14 % in water. It is hydrophilic and absorbent. CA fiber can be chemically modified and plasticized with

liquid plasticizer, and it is soluble in an acetone solution when the concentration exceeds 60 % at 25 °C [37, 38]

CA fiber does not have a sharply defined melting temperature. It softens over a range of temperature, instead of melting sharply at a certain point. Advantage is taken of this property in the use of CA as a plastic where it is molded in various ways into the desired shapes by heat, and processes using softening by heat are sometimes employed in the textile industry. Its main advantage for thermal bonding as a binder fiber is its low softening temperature

2.7 Plasticizer

Plasticizer is a chemical added to polymers and resins to impart flexibility, workability, or stretchability, or a bonding agent that acts by solvent action on fibers The primary role of plasticizer is to reduce the rigidity of a plastic; that is, to render it more flexible. Plasticizers form non-chemical attractions (bonds) with polymer chains and are often associated with polarity [8, 16].

Besides providing desirable application properties to polymers, plasticizers lower processing temperatures by virtue of both glass transition temperature depression and internal lubrication Commonly liquids, plasticizers are compatible with their host polymers, but not to the point of complete miscibility Plasticized polymers lend themselves to coating, molding, and spraying in an uncured liquid form, or to calendering, extrusion, and molding when used as a polymer melt [39].

In nonwoven processing, two different kinds of plasticizer can be used to modify the softening temperature of the binder fibers. These are internal and external plasticizers.

2.7.1 External Plasticizer –Solvent Pre-treatment

A solvent can be used to break the interactive forces between polymer molecules, and replace them with polymer-solvent interactions. The solvent can penetrate the noncrystalline structure of the fiber, break the intermolecular bonds, increase the segmental mobility of the polymer that leads to the molecular relaxation, and lower the glass transition temperature Semicrystalline and oriented polymers often swell in the solvent instead of dissolving because the crystalline structure inhibits the segmental motion and limits the network chain separation unless high solvent concentration or high temperature is used [40] The solvent can also depress the melting temperature of polymer, but the degree of depression will depend on the amount of solvent and the degree of interaction between solvent and polymer. Acetone vapor and 20 % acetone concentration have been used in previous studies as a plasticizer for cellulose acetate fiber, resulting in thermal bonding of cotton/cellulose acetate at reduced softening temperature [41, 42] Celanese Acetate has used aqueous treatments prior to thermal bonding [47] and noted that the use of water lowers the temperature needed in calendering cellulose acetate fibers

2.7.2 Internal Plasticizer

Instead of a solvent pre-treatment, an internal plasticizer can be applied during fiber manufacture to modify chemically the cellulose acetate to lower the softening temperature and to make it possible to bond at a lower processing temperatures.

2.8 Characteristics of Thermal Bonding Process

The first thermally bonded nonwovens were produced in the early 1940s, the carrier fiber was rayon, and plasticized cellulose acetate or vinyl chloride was applied as the binder fiber [46] However, the technology at that time was not developed very well and the cost for available binder fibers was very high. It is not economically to use thermal bonding compared to latex bonding With the increase in energy cost and the development of technology, manufactures began to produce new binder fibers and carrier fibers These made it possible to produce more products incorporating thermal bonding.

Thermal bonding offers certain advantages over latex bonding It decreases energy costs by eliminating the drying process, a required step in the application of wet adhesives. It is a clean operation and minimizes the irritations to eye and skin, and it is an energy efficient process [43, 44, 45]. It can be applied in creating a wide range of products, such as diapers, sanitary products, and medical products.

There are three key components in thermal bonding [46]:

- Structure of carrier or base fiber

- Heat activated binder fiber

- Bonding process

The carrier fiber is the skeleton structure of the nonwoven fabric. It gives the fabric strength, integrity, and certain properties depending on the fiber composition.

The binder used in the thermal bonding process may be a fiber, binder sheaths in a sheath-core bicomponent fiber, powder, film, hot melt, netting, or the outer surface of a homogeneous carrier fiber [46] The physical properties of the thermal binder fibers, when they are used and deposited in and around the fibrous matrix, affect the ultimate product properties as does the thermal bonding process itself.

All thermal bonding processes have two common features:

- The melting point of the binder fiber must be lower than that of the carrier fiber

- Heat must be applied either alone, combined with pressure, followed by pressure- -as in the case of calenders, ovens, and radiant heat sources - or simply generated as part of the process (e.g. ultrasonic bonding)

Bonds formed by thermal bonding are tight, stiff, unyielding, and as solvent-resistant as the polymer or polymers present in the bond. The product, however, can be anything from stiff to soft, closed to open, and thin to bulky, depending on the thermal-bonding options used for processing [43, 44, 45, 46].

There are four different processes in the category of the thermal bonding process:

1. Hot Calender Bonding

There are three different hot calendaring bonding methods according to the achieved bonding structure.

- *Area bond hot calendering*: This process uses a calender with one hot metal roll and another roll which is made of cotton, woolfelt, or some special composition The resulting fabrics are generally thin, closed, inelastic, strong, and stiff.

- *Point bond hot calendering*. This process uses a calender composed of one patterned metal roll and one smooth metal roll. It has the same binder options as for area bonding, or incorporates hot melts or netting These nonwoven fabrics have a wide range of properties from thin, closed, inelastic, strong, and stiff to open, bulky, weak, flexible, and elastic The final properties depend on the frequency and the size of the bonding points as well as the bonding surface in the hot calender. Point bond calendering is the most common method of the thermal bonding process

- *Embossing hot calendering*. This process is basically a figured or sculptured area bond in hot calendering except that the area of bonding here is three-dimensional

2. Thru-Air Oven Bonding

The thru-air oven bonding process applies hot air to the surface of the nonwoven fabric in an oven. A negative pressure across the nonwoven web causes the flow of hot air to pass through the fabric. It applies binders such as crystalline binder fibers,

powders and bi-component fibers Products made by thru-air oven bonding tend to be bulky, open, soft, strong, extensible, breathable, and absorbable.

3. Ultrasonic Bonding

The ultrasonic bonding process applies rapidly alternating compressive forces to localized areas of fibers in the web The stress built up from these compressive forces is converted to thermal energy, which makes the fibers soften as they are pressed into each other. Ultrasonic bonding can be applied in making products such as quilts and outdoor jackets. They are soft, breathable, absorbable and strong.

4. Radiant Heat Bonding

The radiant heat bonding process contributes to web bonding by exposing thermoplastic binder fibers to a source of radiant energy in the infrared range. This is a favored method of bonding of powder-treated nonwovens because of claimed economy of energy sources, energy equipment, and energy use in processing [46] Generally speaking, powder-binder products made in this manner are soft, open, absorptive, and reactive

In conclusion, thermal bonding has become an increasingly important technology in nonwoven applications It is a hot calendering process used in the nonwoven industry which is much less energy intensive, kinder to the environment, and more economical than latex bonding [46, 48]. Although a variety of other hot bonding processes can be

used, hot calendering is one capable of producing fabric with integrity using a simple manufacturing process [49].

2.9 Cotton Based Nonwovens

Cotton is the "king of fibers" because of its various good properties. It is the fiber preferred by consumers and, also, there are several factors that make it important to nonwoven products Cotton nonwoven fabrics can be recycled, re-used or disposed of by natural degradation conditions Cotton is a really renewable resource with long-term supply assurance [50]

The U S Department of Agriculture grapples with problems of improving the cotton fiber, lowering processing costs and exploring new concepts for converting cotton into yarn, wovens, knits and nonwoven fabrics [3]. Cotton is finding its way into nonwoven applications, which have been traditionally dominated by synthetic fibers Within the last decade, bleached cotton fiber suitable for processing on conventional nonwoven equipment has become available and has substantially increased the interest in this fiber. The thermal calendering process is usually selected to make cotton-based products because of its process simplicity, reduced production costs, and improved fabric property [51]

Synthetic fiber manufacturers have also raised the interest in cotton usage by suggesting and promoting thermal binding fibers that can be blended with cotton fiber and be heat-treated to provide nonwoven fabric stability. In 1937, thermoplastic fibers were first used as binder fibers in nonwoven processing shortly after the synthetic fiber vinyon was made

available commercially [52]. Then, many thermoplastic fibers, such as olefin fibers, cellulose acetate, nylon, and polyester, came into use as binder fibers, all of which provide effective bonding for dry-laid nonwovens when dispersed with the matrix fibers in the web

Specific programs for research involving the use of bleached cotton in heat bonding configurations are in process at The University of Tennessee, in Knoxville and at the U S D A Southern Regional Research Center in New Orleans. In 1987 at University of Tennessee-Knoxville, Duckett and Wadsworth [26] initiated the first research program focused on the formation of stable nonwoven fabrics through the thermal calendering of cotton and polyester staple fiber blends The evaluation of tensile properties of fabrics bonded by smooth-roll calendaring was used as a criterion for thermal bonding effectiveness The results showed that the fabric strength is sensitive to both calender crush edge pressure and temperature However, the hand and stiffness of the fabrics were considered harsh for some applications. This was attributed to the uniform melting of the binder fiber throughout the fiber blend and compression resulting from smooth roll calendering.

In 1988, Duckett and Wadsworth [4] furthered the study of thermal bonding on carded blends of cotton and polyester binder by point-bond calendering, in order to produce fabrics with better hand qualities. The result shows that nip roll pressure in the range of 65 to195 KN/m did not contribute much to the fabric strength. The calender roll temperature and the roll speed had a great effect on the fabric strength

In 1989, Duckett [53] and his group also examined how different surface treatment on the cotton surface affected the tensile strength of cotton/polyester thermally bonded fabrics. The result showed that the scoured and bleached cotton fibers, without an additional surface treatment gave the best tensile properties for the thermally bonded fabrics.

In 1994, bicomponent fiber was introduced into cotton based nonwovens research by Duckett and Sharma [54]. Two different binder fibers were used. Both of them were a sheath/core structure with polyester as the core material. The sheath materials were polyethylene(PE) and polyester(PET), respectively, with very low softening temperature. The PE/PET bicomponent fiber had a surface softening temperature in the range of 100-105 °C and PET/PET bicomponent fiber had a surface softening temperature between 75 °C and 85 °C The study showed that fiber type and sample preparation methods affected the physical properties of the fabric

In 1994, Wadsworth and Duckett, et al [55] developed a new use of cotton fibers for the nonwovens industry They used cotton fibers as core materials and laminated it with meltblown (and/or spunbond) webs using thermal calendering to produce a nonwoven laminate.

With the increasing concern for the environment and the need of biodegraded nonwoven disposable products, Duckett, Bhat and their group [56] began to seek biodegradable fibers as binder fibers to replace synthetic binder fibers previously used for cotton based nonwoven roll products In 1995, biodegradable nonwovens from cotton/cellulose acetate blends with the basis weight of 160 g/m^2 were made by thermal bonding using

bonding temperatures in the range of 180° C to 240° C. The tensile strength over the whole bonding temperature range was about 7.5 mN/tex, except for 230 °C. However, the level of desirable tensile properties had not reached; it may due to the basis weight of the web, which is too heavy for sufficient heat transfer during calendering. Acetone solvent vapor pretreatment was applied in this case with bonding temperatures at 170-180 °C. Different vapor pretreatment times were examined. Without solvent vapor treatment, the tensile strength was only 4 mN/tex. After the pretreatment, an enhanced tensile strength of 11 mN/tex was observed at the same temperature, showing the significant effect of solvent vapor pretreatment on enhancing the bonding at relatively low bonding temperature This was primarily attributed to lowering the softening temperature of cellulose acetate In an even later study [42], a 20% and 40% concentration of acetone solvent was used as the treatment of a cotton/cellulose acetate web with basis weight at 1 ounce/yard^2 before thermal calendering. The bonded fabric resulted in tensile properties around 9 0 mN/tex at 190 °C

This research seeks a new plasticizer to either replace acetone pre-treatment or eliminate the use of pre-treatment.

3 EXPERIMENTAL PROCEDURES

3.1 Fiber Selection and Properties

There are three different kinds of fiber involved in this research. Cotton fiber is the base fiber, and two types of cellulose acetate fiber are selected to be the binder fiber One is ordinary cellulose acetate (OCA) and the other is plasticized cellulose acetate (PCA).

The cotton fiber used in this research is a scoured and bleached cotton fiber provided by Cotton Incorporated. It has a 5 2 % moisture regain value, 5 4 micronaire value and an upper-half-mean fiber length at 2.44 cm Celanese Corporation provided both ordinary cellulose acetate (OCA) and plasticized cellulose acetate (PCA)

These three kinds of fibers have been tested by various methods, and their properties are shown in the table 3.

Table 3 Properties of Selected fibers

	Cotton	**OCA**	**PCA**
Thickness (nm)	5500	6250	7750
Birefringence	0 04327	0 00448	0.00452
Mean Fiber length (inch)	1 02	1.65	1 77
Denier	2 175	1.116	2 88
Softening Temperature (°C)	-	~190	~110
Cross-section	Bean shape	Pop-corn shape	Tri-lobe shape

3.2 Experimental Design

The experiment was a four-factor design with two replications. The factors included are.

- CA type: Ordinary CA(OCA) and Plasticized CA(PCA)
- Temperature: 150°C, 170°C,190°C
- Blend Ratio: Cotton/Cellulose Acetate = 75/25 and 50/50 (weight ratio)
- Pre-treatment Without Water Treatment

  Water Spray Treatment

  Water dip-nip Treatment

  20% concentration Acetone Treatment

There are all-together 2×3×2×4×2 = 96 experiments.

3.3 Process Procedures

There were three major process procedures in the experiment, carding, water pre-treatment, and thermal calendering. The whole processing procedure is shown in Figure 6 and the processing machinery used in this research are pictured and shown in Appendix-1.

3.3.1 Opening, Blending, and Carding

Fibers were first opened by hand, and then each fiber type was weighed according to the blend ratio and desired basis weight of the nonwoven fabrics. An ultra-light fabric with basis weight around 1 ounce/yard^2 was chosen for this research.

To achieve 1 ounce/yard^2 webs, a fiber input was calculated according to the blend ratio, and the total mass input of the two fibers(C/CA) near 12 g was obtained using a precision balance ($\pm$ 0.1 g). To avoid electrostatic problems and to obtain a homogeneous web, the fibers was mixed and a sandwich structure of fiber layers was formed by hand This layered structure had two layers of cotton on the outside and one layer of CA between two cotton layers prior to placement in the feed tray at the licker-in of the card

A Saco-Lowell carding machine was used to form the carded webs The collector drum circumference was 56"(142.2 cm) and the drum width was 8.75"(22.2 cm). The carded webs were then cut away from the drum and placed between two sheets of paper await for pre-treatment and thermal calendering.

3.3.2 Water Treatment

An H.W Butterworth & Sons padding machine was used for the water pretreatment. The carded webs were placed between two fine mesh screens, and passed through a tray containing water before going through padding rolls to squeeze out of extra water. The padding roll pressure was set at 60 psi.

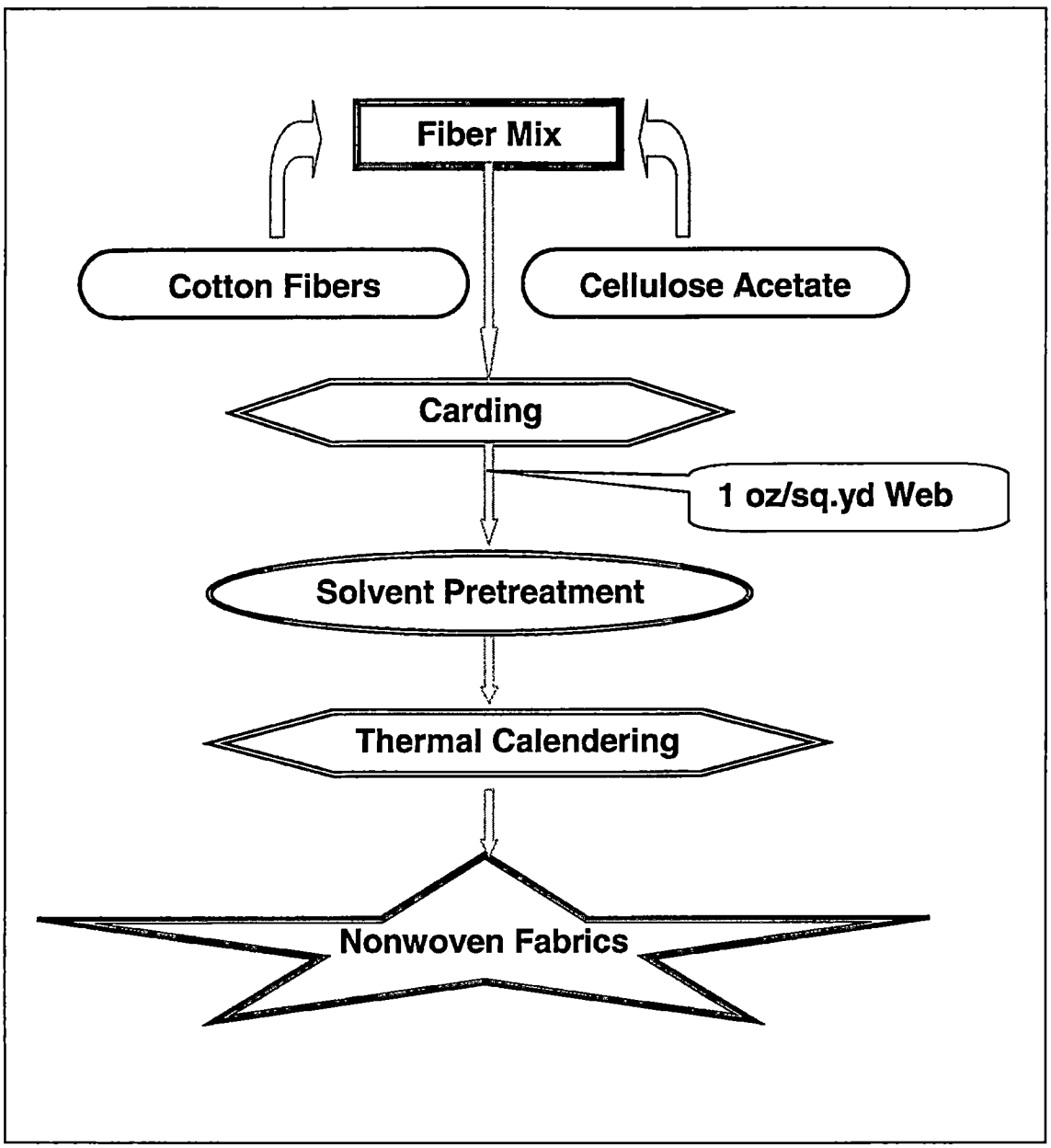


Figure 6 Flow Chart of Processing Procedures

Since the water-treated web was so wet, it was thought that the evaporation of excess water may significantly decrease the bonding temperature Thus, two layers of paper-towels were placed on the upper and lower sides of the mesh screen The combined layers were run through the padding machine again so that the excess water could be absorbed by the paper towels. Hereafter, this process is referred to as a water dip-nip. After this procedure, the webs were ready to be thermal calendered

3.3.3 Thermal Calendering

A Ramisch Kleinewefers 23.6"(60 cm) wide five-roll calender was used Only the upper two rolls were used. The top calender roll had an engraved diamond pattern resulting in 16.6 % bonding area. The bottom roll was smooth and both were made of stainless steel The rolls were heated by circulating oil and the nip roll pressure was set at 25 KN, the roll feed speed was fixed at 10 m/min.

For the experiment, three bonding temperatures were selected around the softening temperature of the cellulose acetate binder fibers. They were 150 °C, 170 °C and 190 °C.

The leading edge of the webs, when removed from the mesh screen, was attached to a brown paper leader using water. This paper leader allowed the web to pass into and through the nip edge of calendering rolls. The process is shown in Figure 7.

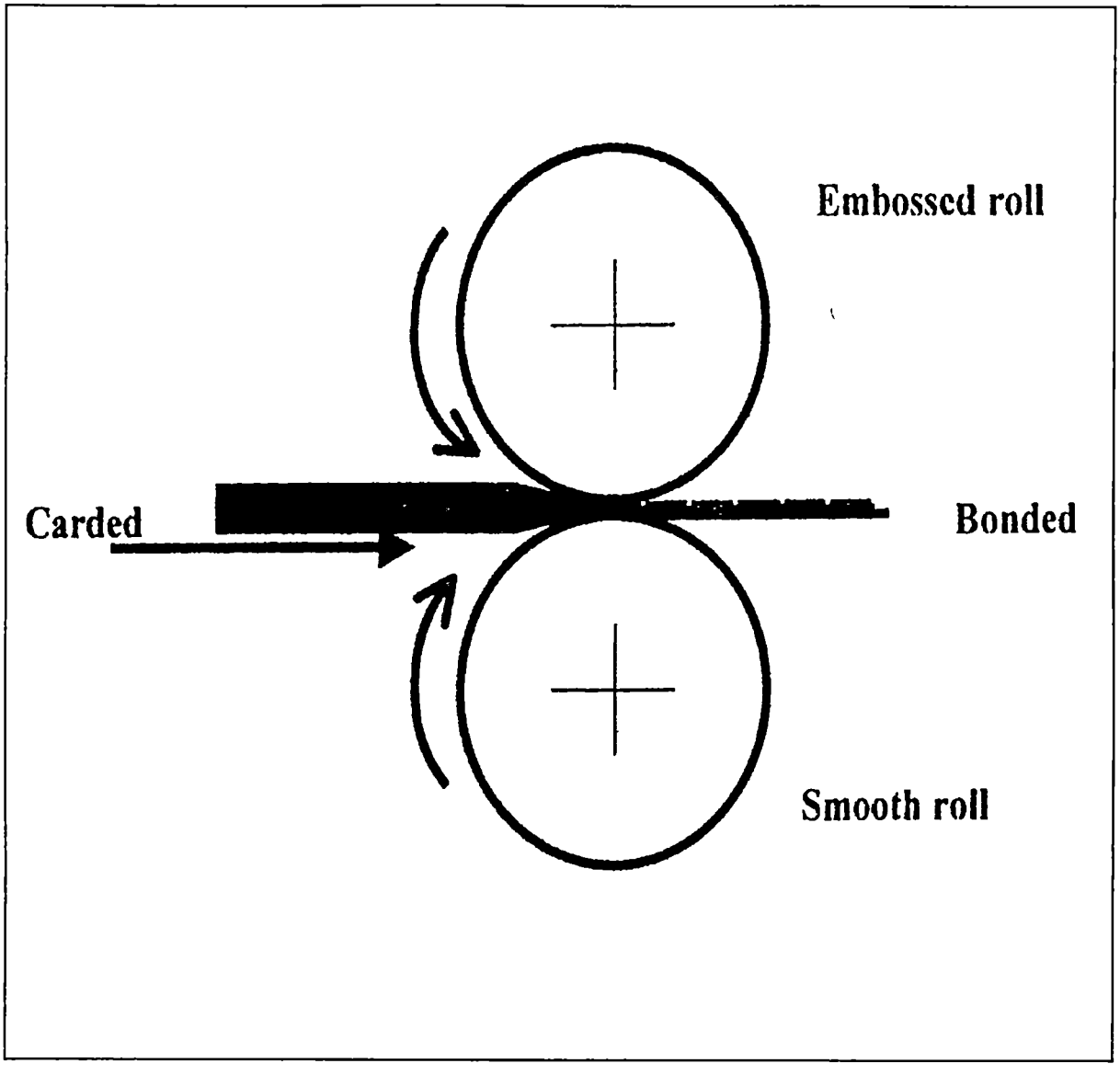


Figure 7 Thermal Calendering Process

3.4 Characterization of Nonwoven Fabrics

All the webs were laid out separately until they dried Then, they were moved to the testing room in a standard atmosphere of 65±2 % RH, 70±2 °F (21±1 °C) [34] for textile testing After 24 hours of conditioning, samples were cut along the machine direction. Cross-direction samples were not obtained due to the limited size of web area. Each test consisted of a standard according to ASTM D1117 – 80 Standard Methods of Testing Nonwoven Fabrics.

3.4.1 Basis Weight

Two 7"×7" samples were cut from each nonwoven fabric, and weighed The average values of weight measures were calculated and divided by the area to get the basis weight (g/m^2) of the fabric. This followed IST 130.1 –92 Standard Test Method for the Mass Per Unit Area of Nonwoven Fabrics.

3.4.2 Fabric Thickness

Following ASTM D 1777 – 64 Standard Test Method for Measuring Thickness of Textile Materials, twenty-five measurements were made using a TMI 49-70-00 Micrometer and an average value was calculated as the web thickness.

3.4.3 Fabric Flexibility (Cantilever Method)

According to ASTM D 1388 – 64 Standard Test Method for Stiffness of Fabrics, four 1"×6" specimens were cut and tested using the F R.L. Cantilever Bending Tester with

inclination angle of 41.5 ° The bending length (c) is exactly a half-length of the fabric that overhangs the edge and bends under its own weight. Each test specimen was measured with four readings on each end on both sides Flexural Rigidity (G), a measure of the interaction between weight and stiffness, was calculated using the equation:

$$G = W \times c^3$$

where W is the fabric mass per unit area (mg/cm^2) Results were reported in mg cm

3.4.4 Fabric Tensile Properties

The method followed ASTM D 1117 – 80 Standard Test Method for Tensile Testing of Nonwoven Materials. Five 1" × 10" test specimens were cut from the web along the machine direction. A United Tensile Tester, constant-rate-elongation (CRE) type, was used to obtain the tensile measurements on each of the five test specimens. The gage length was set at 5 inches and the testing speed was 5 inches/min. Tensile properties such as peak breaking load, peak strength, and peak elongation were recorded.

3.5 Scanning Electron Microscopy

Certain bonding structures and strengths result from going through the thermal calendering machine. The pattern roll generates small diamond bonding points on the web. The bonding points are the place where the binder fiber was heated, compacted, and bonded to cotton fiber or other binder fiber to form the bonding area. Information of bonding structure and the fiber morphology is useful for understanding the fabric tensile

strength change SEM provides this information and a Hitachi S-800 SEM was used to examine the bonding points, bonding rupture and fiber structure. Samples were prepared by cutting the fabric with the same area as the sample holder The bonding points and inside fibers were found and examined under SEM. Clear pictures of bonding points and fiber surfaces were provided by setting SEM at 1 Kev, 7 mm working distance, and magnification of 80× and 250× , separately

3.6 Statistical Analysis

The effect of CA type, temperature, blend ratio and treatment type on the peak strength were analyzed as a full four-way factorial analysis of variance with two replications All the data analysis was performed with SPSS 10.0 software. The analysis syntax was listed in Appendix-2 and the statistical analysis results are gathered in Appendix-3

4 RESULTS AND DISCUSSION

The results discussion has been focused on the effects of plasticizer type (cellulose acetate type, solvent treatment type), temperature, and blend ratio on the tensile properties - especially the peak strength of the calendered cotton/cellulose acetate web in the machine direction.

Cellulose acetate is hydrophilic and thermally bondable. It has a softening temperature of approximately 200 °C and a melting point around 260 °C The plasticizer was introduced – either externally as in our work or internally as in the case of industrial preparation - in order to lower the softening temperature of cellulose acetate to make it thermally bondable with cotton fibers at reduced temperature

The internal plasticizer, the external plasticizer (water) and their combined effect on the nonwoven web's tensile properties and, to a lesser extent, flexural rigidity are studied. Statistical analysis is used to test the significance of the difference and SEM photographs are used to examine the bonding point morphologies under the different treatment and processing conditions.

4.1 Plasticizer Effect

4.1.1 External Plasticizer Effect

A Water Spray treatment

Part of the purpose is to determine selected optional process conditions by experimentation before a large scale experiments is carried. Water was selected as the external plasticizer due to its promising plasticizing effect At the first step of study, a water-spray pretreatment was applied as an external plasticizer on the web before it was calendered. The effect of water on fabric strength was studied under different blend ratios of cotton/ordinary cellulose acetate (OCA). The experimental design is shown in table 4. The results are presented in Figure 8 and Figure 9

Table 4 Experimental Design of Water Spray Pretreatment Trial on C/OCA Blends

Blend Ratio of C/OCA	Pretreatment	Temperature	Result
50/50	Water Spray	150°C	Figure 8
		170°C	
		190°C	
	No Water	150°C	
		170°C	
		190°C	
75/25	Water Spray	150°C	Figure 9
		170°C	
		190°C	
	No Water	150°C	
		170°C	
		190°C	

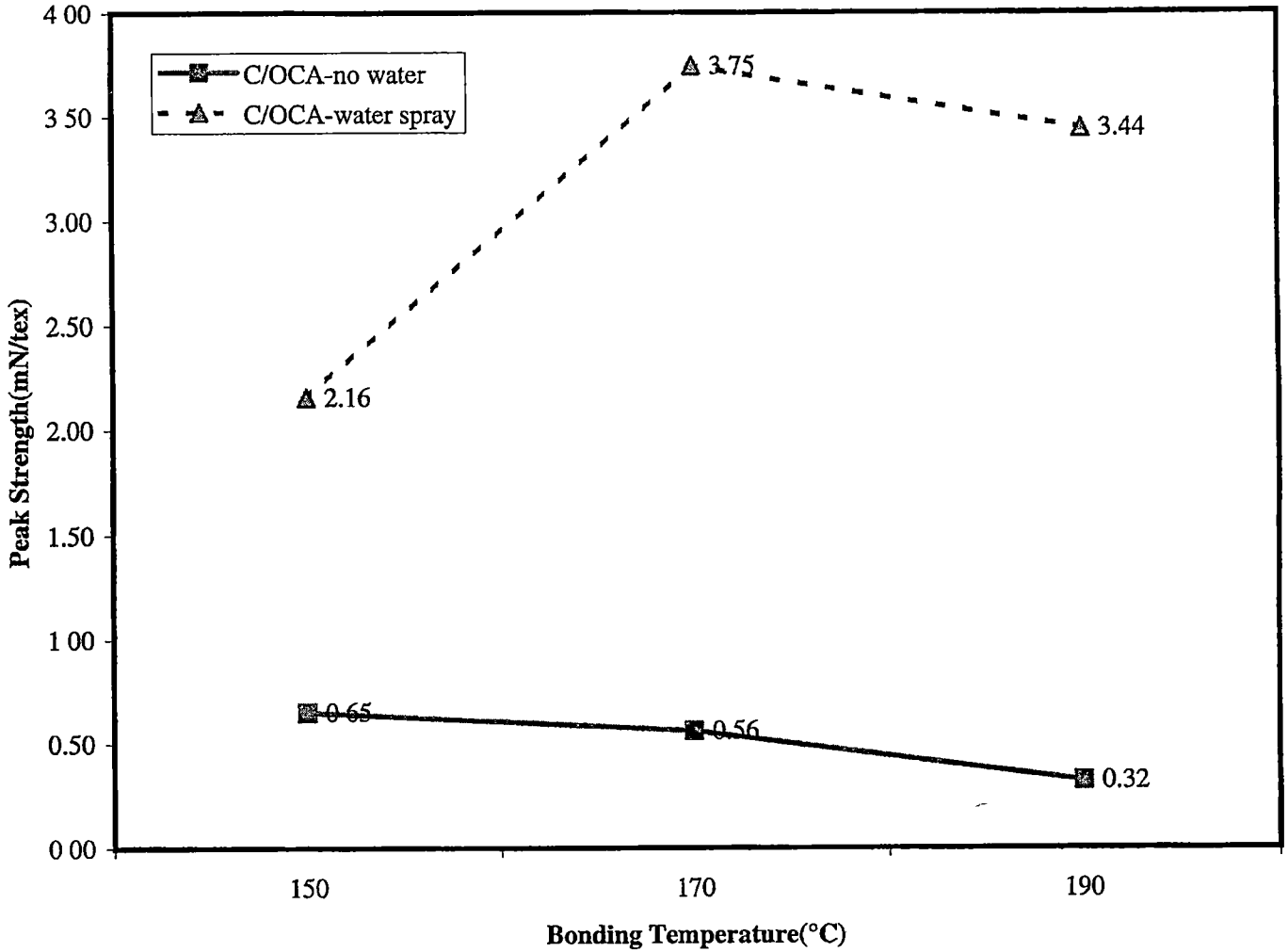


Figure 8 Effect of Water Spray Pretreatment on the Peak Strength of C/OCA-50/50 Web

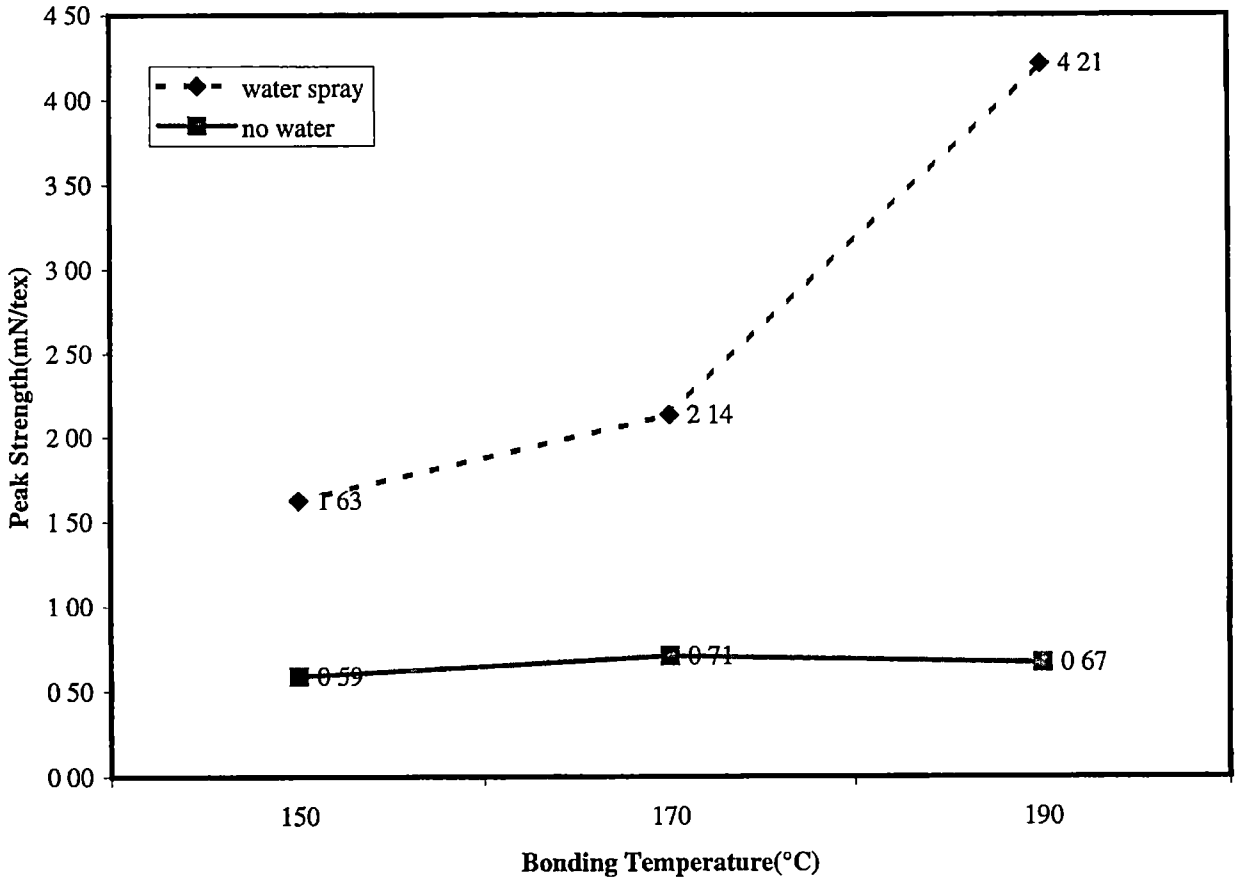


Figure 9 Effect of Water Spray Pretreatment on the Peak Strength of C/OCA-75/25 Web

For both blend ratios, 50/50(Figure 8) and 75/25(Figure 9), one can see similar trends where the peak strength of the fabric bonded after water spray treatment is higher than those of fabrics without any treatment. This immediately demonstrates the positive contribution of water treatment to fabric strength. Furthermore, when there is no water treatment, the fabric peak strength shows no change with the increase of bonding temperature. That is attributed to the roll temperatures being lower than the softening temperature of ordinary cellulose acetate

For the fabric with water spray treatment, there is a gradual increase in the peak strength with each increasing bonding temperature compared with those having had no water spray treatment. This is highly suggestive and illuminating because it shows the possibility that water will act as a plasticizer to enhance the fabric tensile properties at lower bonding temperature. However, the tensile properties are still unexpectedly low even with water spray treatment. The reason may be that the water cannot be sprayed and distributed in the web very uniformly to result in better bonding. A submersion process rather than a spray treatment is suggested as an alternative.

B Water Dip-nip treatment

In the second phase of the treatment design, a water dip-nip treatment was used to apply the external aqueous plasticizer to the web The results of comparison between water dip-nip and no water treatment effect on fabric peak strength are shown in Figure 10 and Figure 11, separately for two different blend ratios.

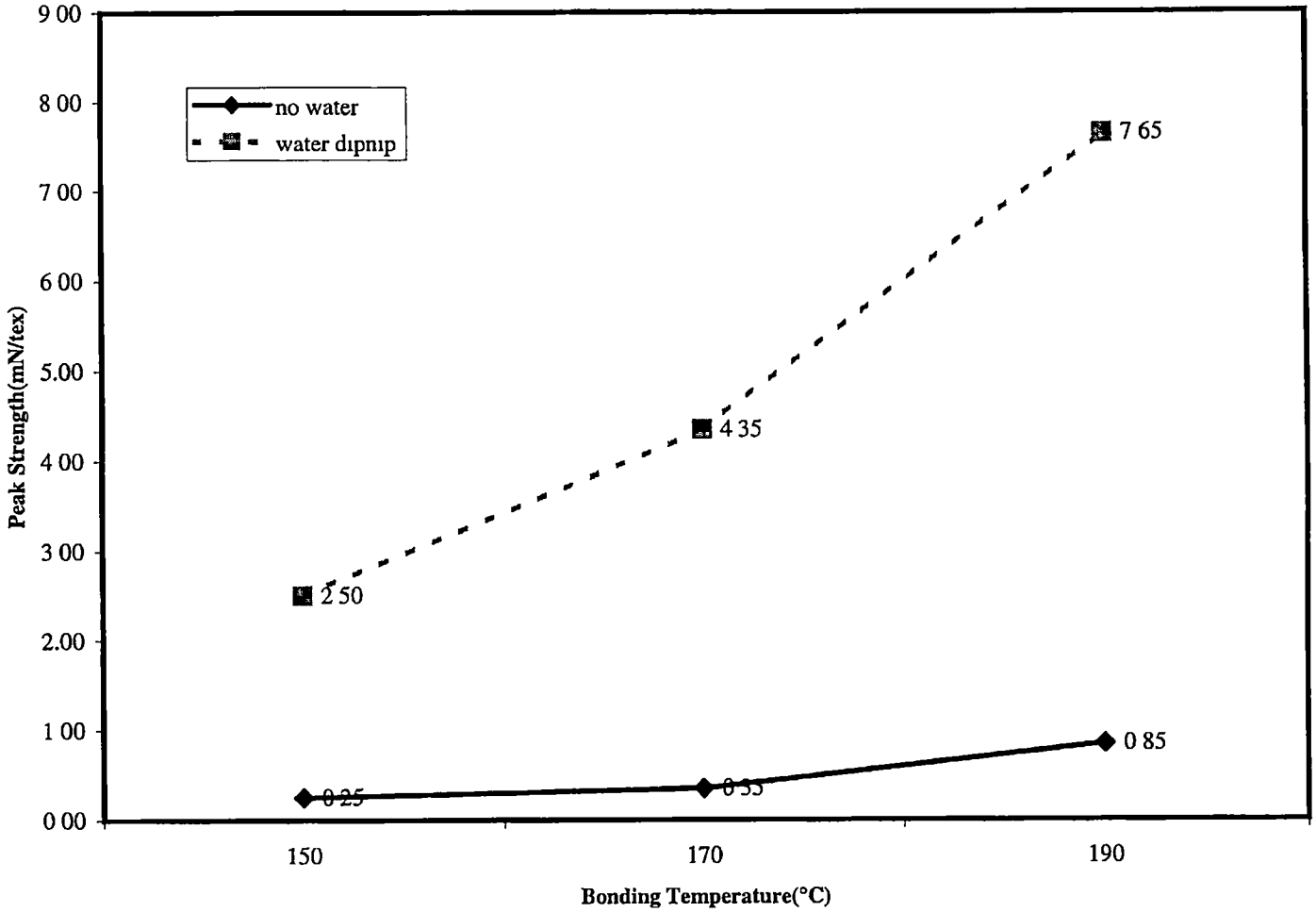


Figure 10 Water Dip-nip Effect on the Peak Strength of C/OCA-50/50 Web

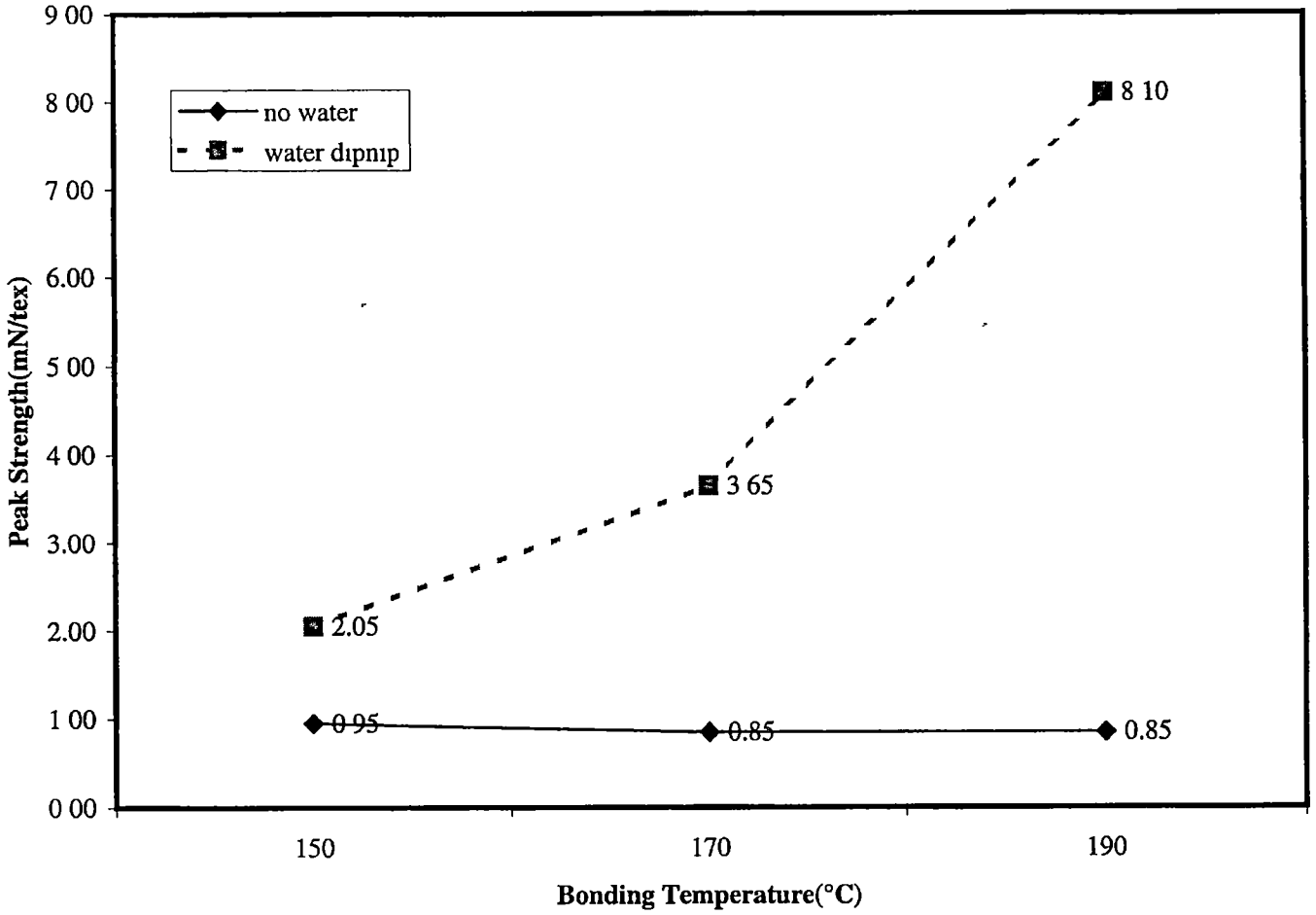


Figure 11 Water Dip-nip Effect on the Peak Strength of C/OCA-75/25 Web

With water dip-nip treatment, the peak strengths of the C/OCA webs at two different blend ratios are increased to different degrees compared with those for which there was no water treatment.

Using statistical analysis (Appendix-3), the following hypotheses were tested under each of the six combination of temperature and blend ratio.

H_0 There is no significant difference in mean peak strength with or without water treatment

H_1 The mean peak strength with water treatment is higher than that without water treatment

The results are shown in Table 5.

Table 5 Statistical Analysis of External Plasticizer Effect on Peak Strength of C/OCA Web

Blend Ratio (C/OCA)	Temperature (°C)	Peak Strength Difference (Water Dipnip vs No Water)	Significance
50/50	150	2 2 mN/tex	*
	170	4 0 mN/tex	*
	190	6 8 mN/tex	*
75/25	150	1 1 mN/tex	-
	170	2 8 mN/tex	*
	190	6 0 mN/tex	*

Note * Reject H_1, based on $\alpha = 0\ 05$

- Accept H_0, based on $\alpha = 0\ 05$

We conclude that the external plasticizer-water, which is applied to the web by a dip-nip treatment, can significantly increase the bonding strength of cotton/cellulose acetate thermally bonded webs with the blend ratio of 50/50. The tensile strength can be increased to 7.6 mN/tex compared with 0.85mN/tex without the aid of a water treatment at 190°C.

The tensile strength of cotton/cellulose acetate with 75/25 blend ratio is also improved by the water dip-nip treatment. The tensile strength can be increased to 8.1 mN/tex compared with 0 85 mN/tex under no water pre-treatment at 190 °C. When the bonding temperature is either 170 °C or 190 °C, the water effect is significant. However, the water did not show a significant effect on the tensile strength of the web at 150 °C where the tensile strength was increased to 2 05 mN/tex as compared with 0.95 mN/tex under no water treatment. This may due to two possible effects:

- The relatively low amount of binder fiber in the web composition at low bonding temperature results in less effective contacting sites in the bonding area compared with those of the 50/50 blend ratio.

- Water evaporation reduces the available heat for polymer flow and this may greatly affect the bonding when the bonding temperature is very low.

Overall, however, there still remains the question of what mechanisms are involved. That is, why are there such great differences on cotton/cellulose acetate web tensile strength by introducing an external plasticizer? There are several ideas, for example.

1. Water molecules penetrate the whole web, with the assistance of padding machine As is known, water molecules are small and possess hydroxyl groups, which can attract the cellulose acetate molecule by hydrogen bonding. Thus, the intermolecular forces of cellulose acetate are reduced, and the mobility of the polymer chains is improved. The polymer becomes elastic and more flexible, with the result that the softening temperature is lowered. Hence, the softening temperature can be brought down by the external plasticizer-water dip-nip treatment, providing increased cellulose acetate molecular mobility and reducing the necessary thermal energy required to bond the fibers at the fiber cross-over points. This makes it possible to bond at lower temperature, with the aid of a water dip-nip pre-treatment.

2. Due to the hydrophilic nature of the partially crystalline structure of cellulose acetate, it can take up substantial water. Above the softening temperature, the fiber swells as a result of molecular chain relaxation and becomes sufficiently tacky to provide some bonding with other binder fibers and with the base fiber. The swelling, which provides greater free volume for the polymer, will increase the surface area and enhance contact with the other fibers. This might increase bonding strength by providing more bonding area at the bonding point.

3. When the web is passed through the nip of the pattern and smooth rolls of the thermal calender, heat and pressure are applied to the web. The web at that time is composed of cotton fiber, cellulose acetate fiber, and water. Water has very good thermal conductivity, which is about ten times that of acetone. When the web is contacted with the heating roll under pressure, some water in the web evaporates immediately

The vapor provides additional force for the penetration of liquid water into the structure, leading to additional heat at the bonding points and enabling more polymer flow to achieve better bonding.

The external plasticizer-water bonds physically to the polymer rather than chemically (covalently), which lowers the softening temperature of cellulose acetate. In combination, this enables more heat and polymer flow at the cross-over points of fibers in the bonding region, providing good tensile properties to the web under lower bonding temperature.

C. Comparison of Water Dip-nip Treatment and Acetone Treatment

In former research carried out at The University of Tennessee, different kinds of external plasticizer and treatments methods were applied These included an acetone vapor treatment and a 20% acetone solution dip-nip treatment. In order to get an idea of how well water works, an experiment was designed whereby water treatment and 20% acetone concentration effects are compared. The results are shown in Figure 12 and Figure 13, separately by different blend ratio.

Using Statistical analysis (Appendix-3), the following hypothesis was tested for each of the six combinations of blend ratio and temperature. analysis results are shown in Table 6.

H_0· There is no significant difference in mean peak strength with water dip-nip treatment and with 20% acetone concentration treatments

H_1 There is a significant difference in mean peak strength under different treatments

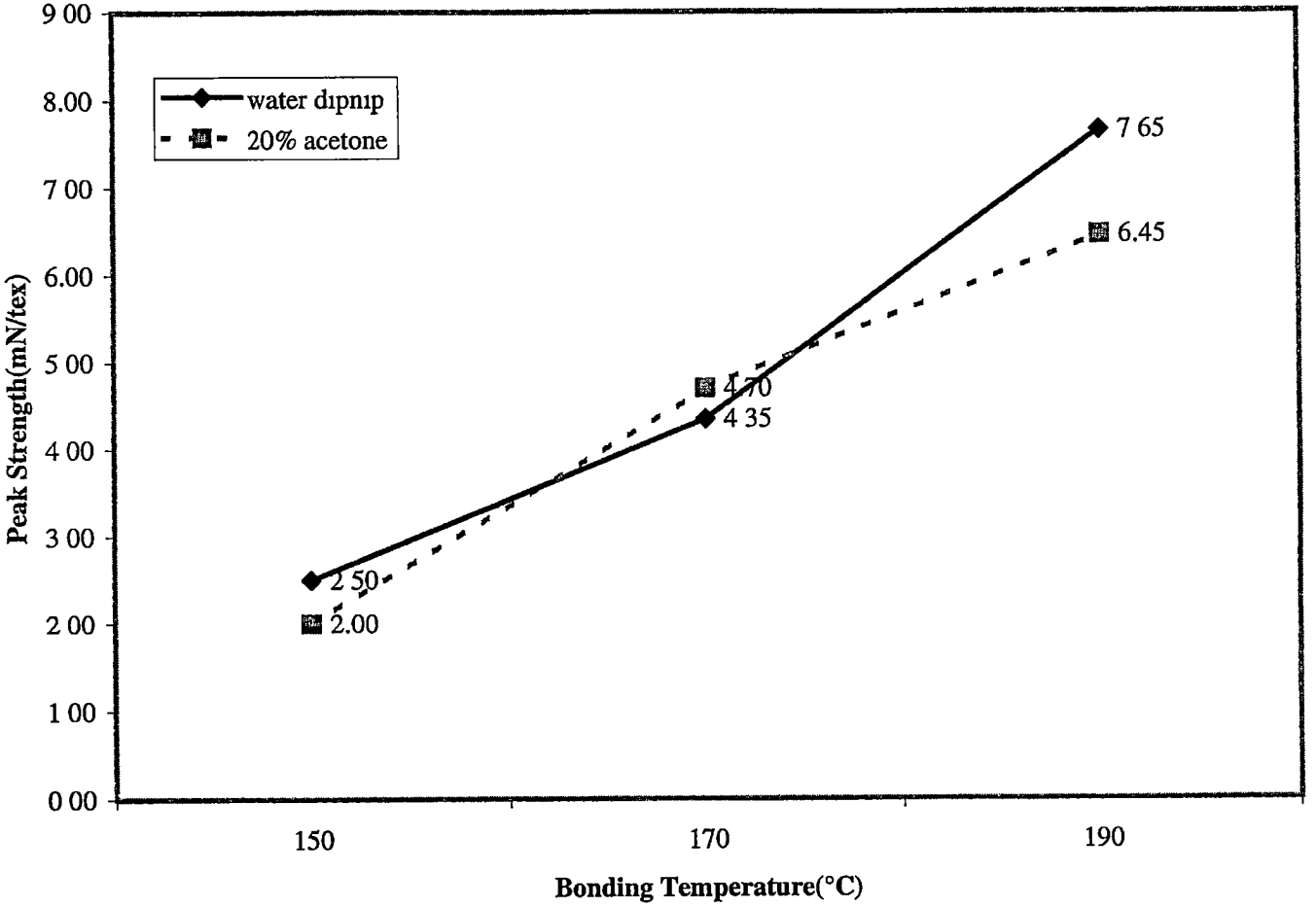


Figure 12 Different Solvent Treatment Effect on C/OCA-50/50 Web

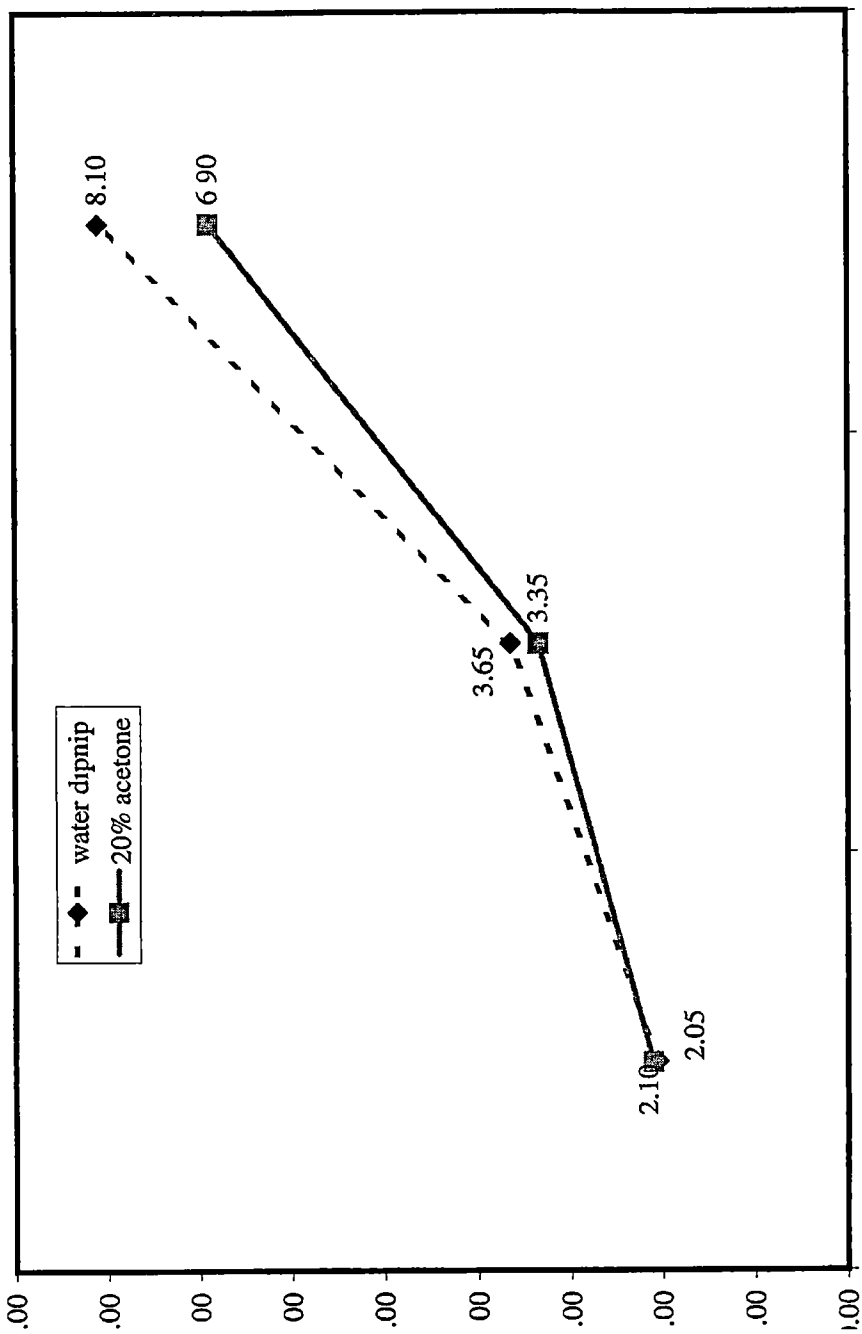


Figure 13 Different Solvent Treatment Effect on C/OCA-75/25 Web

Table 6 Statistical Analysis of Different External Plasticizer Effect on Peak Strength of C/OCA Web

Blend Ratio (C/OCA)	Temperature (°C)	Peak Strength Difference (Water Dip-nip vs. 20% Acetone)	Significance
50/50	150	0 50 mN/tex	-
	170	-0 35 mN/tex	-
	190	1 20 mN/tex	-
75/25	150	0 05 mN/tex	-
	170	0 30 mN/tex	-
	190	1 20 mN/tex	-

Note * Accept H_1, and reject H_0, based on $\alpha = 0\ 05$

- Accept H_0, and reject H_1, based on $\alpha = 0\ 05$

We can clearly conclude for this experiment that there is no significant difference between the two different kinds of external plasticizer – water and 20% acetone when applied to the web by dip-nip pretreatment. Both plasticizations, however, do increase the bonding strength of cotton/cellulose acetate thermally bonded webs. The results here suggest that water can replace a 20% acetone concentration and be used as the external plasticizer to cotton/cellulose acetate web, without degrading web strength This would eliminate many industry concerns caused by using acetone, which is toxic and has an unpleasing odor

As a side, none of the external plasticizer treatments significantly changed the peak elongation at 150°C At this temperature, the bonding structure is weak. At 190°C, there is no significant peak elongation increase when the water treatment is replaced by acetone treatment Both of these external plasticizer treatments will increase significantly the peak elongation above those thermally bonded fabrics without any pretreatments.

The interpretation is that the higher the temperature, the better the bonding structure. Fibers in the strong bonding points do not break during fabric stretching and the fibers are able to redistribute the overall load So the peak elongation will be increased by the external plasticizing effect

4.1.2 Internal Plasticizer Effect

From the standpoint of industry, it is best to make the process as simple as possible. The applications required by water dip-nip treatment of an external plasticizer make the process complicated. However an internal plasticizer introduced during fiber manufacture whereby the structure of cellulose acetate fiber is modified to lower the softening temperature of the substance comprising the fiber may have benefit

The principle of an internal plasticizer involves monomers, which lead to homopolymers with high transition temperature, being selectively copolymerized with monomers whose homopolymers have a low glass transition temperature [57, 58, 59]. One of the plasticized cellulose acetate processes for accomplishing fiber-sized filaments is detailed in a process patented [60] in 1996 by Mulhaupt et al in Germany. This plasticized cellulose acetate has a component of a grafted oligomer of a cyclic ester, in particular, in the form of caprolactone.

The effect of an internal plasticizer on the peak strength of Cotton/PCA blend was examined in this research. The results are shown in Figure 14 and Figure 15, separately by different blend ratio.

From these two figures, it is observed that the web containing plasticized cellulose acetate (PCA) binder fibers has higher peak strength than those comprising ordinary cellulose acetate(OCA) binder fibers. The tensile strength is increased to 9 00mN/tex for C/PCA-50/50 webs. This is to be compared to 0 85mN/tex for C/OCA-50/50 webs at 190°C. This clearly demonstrates that the internal plasticizer enhances the bonding strength of a thermally bonded cotton/cellulose acetate web.

Using statistical analysis (Appendix-3), the following hypothesis was tested for each of the six combinations of blend ratio and temperature.

H_0· There is no significant difference in peak strength between the use of PCA and OCA as binder fibers

H_1 There is a significant difference in peak strength between the use of PCA and OCA as binder fibers.

The results summarized from statistical analysis are shown in table 7.

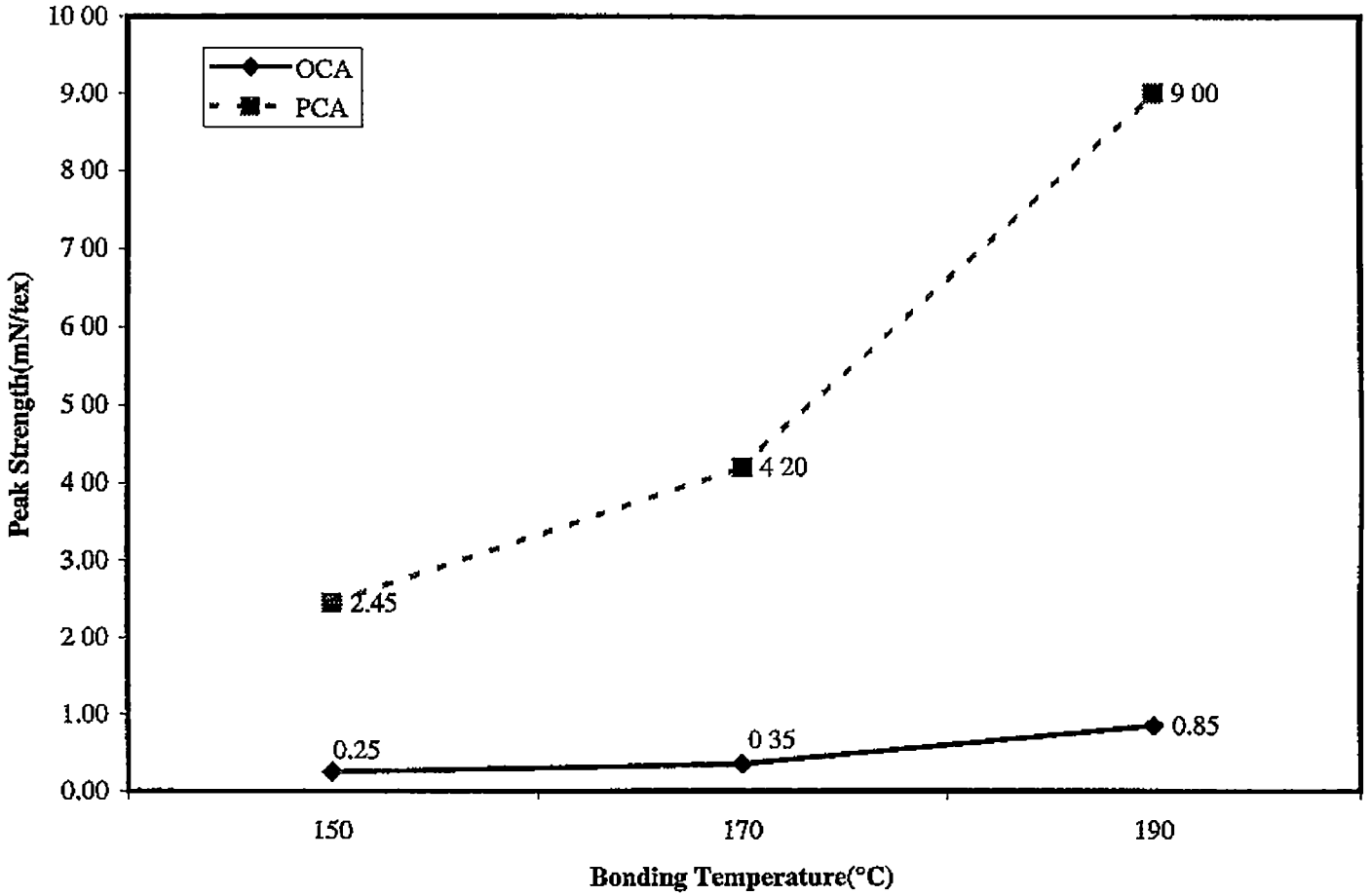


Figure 14 Internal Plasticizer Effect on the Peak Strength of C/CA-50/50 Web

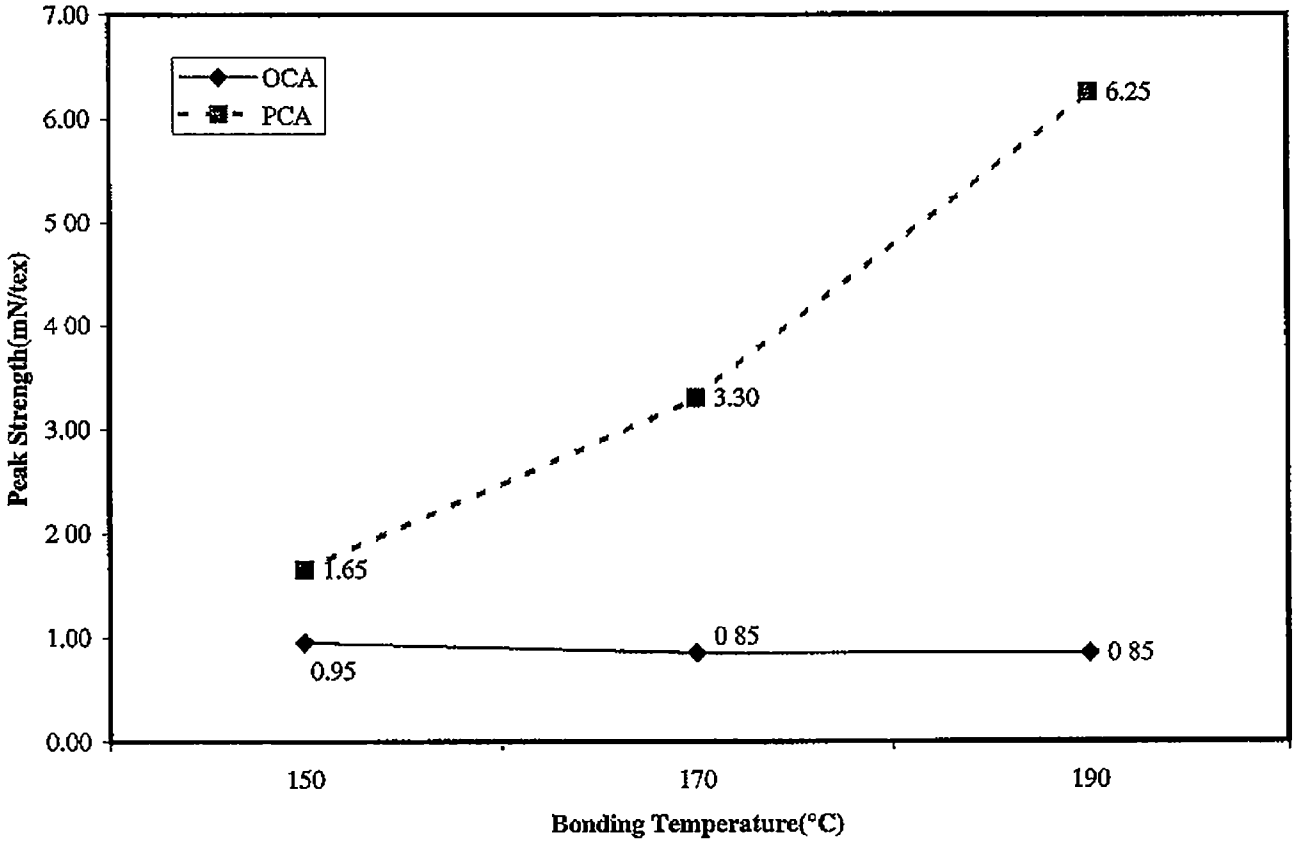


Figure 15 Internal Plasticizer Effect on the Peak Strength of C/CA-75/25 Web

Table 7 Statistical Analysis of Internal Plasticizer Effect on Peak Strength of C/CA Web

Blend Ratio (C/CA)	Temperature (°C)	Peak Strength Difference (PCA vs. OCA)	Significance
50/50	150	2 20 mN/tex	*
	170	3 85 mN/tex	*
	190	8 15 mN/tex	*
75/25	150	0 70 mN/tex	-
	170	2 45 mN/tex	*
	190	5 40 mN/tex	*

Note * Accept H_1, and reject H_0, based on $\alpha = 0\ 05$

- Accept H_0, and reject H_1, based on $\alpha = 0\ 05$

The resultant trend is the same as that seen with the external plasticizer effect. All webs using PCA as binder fibers have significantly higher peak strength than those using OCA as binder fibers, except for the 75/25 C/CA web bonded at 150°C That may be due to the low number of binder fibers and the lower bonding temperature, whereby the web could not get sufficient heat flow and polymer flow to cause a bonding site.

When the bonding temperature is 190°C, the web's peak elongation increased significantly for PCA as the binder fiber compared to OCA binder fiber. However, no significant change is observed at the lower temperature of 150°C.

4.1.3 Combination of Internal and External Plasticizer

The combination of internal and external plasticizer (C/PCA - water dip-nip treatment) was applied to cotton/cellulose acetate webs and their effects studied Three different comparisons were made and the results are summarized in the following ways.

A PCA with water dip-nip vs. OCA without water dip-nip

The effect of the combination of internal and external plasticizer on the web peak strength was compared with that of no plasticizer treated web. The results are shown in Figure 16 and Figure 17, separately by blend ratio.

From these two figures, we observe that.

- A combination of internal and external plasticizer (C/PCA - water dip-nip treatment) on the C/CA webs enhanced the web's bonding.

- The peak strength for both blend ratios bonded at 170°C was increased from about 0 5 mN/tex for C/OCA webs with no treatment to around 8.3 mN/tex.

- The peak strength for both blend ratios bonded at 190°C was increased from 0.85 mN/tex for C/OCA webs with no pre-treatment to about 8.4 mN/tex.

- With the combination of internal and external plasticizer treatments, it is observed that the web achieves a comparable high peak strength at 170°C as that bonded at 190°C. It seems that there is no temperature effect on the web strength between 170°C and 190°C This is supported by statistical analysis

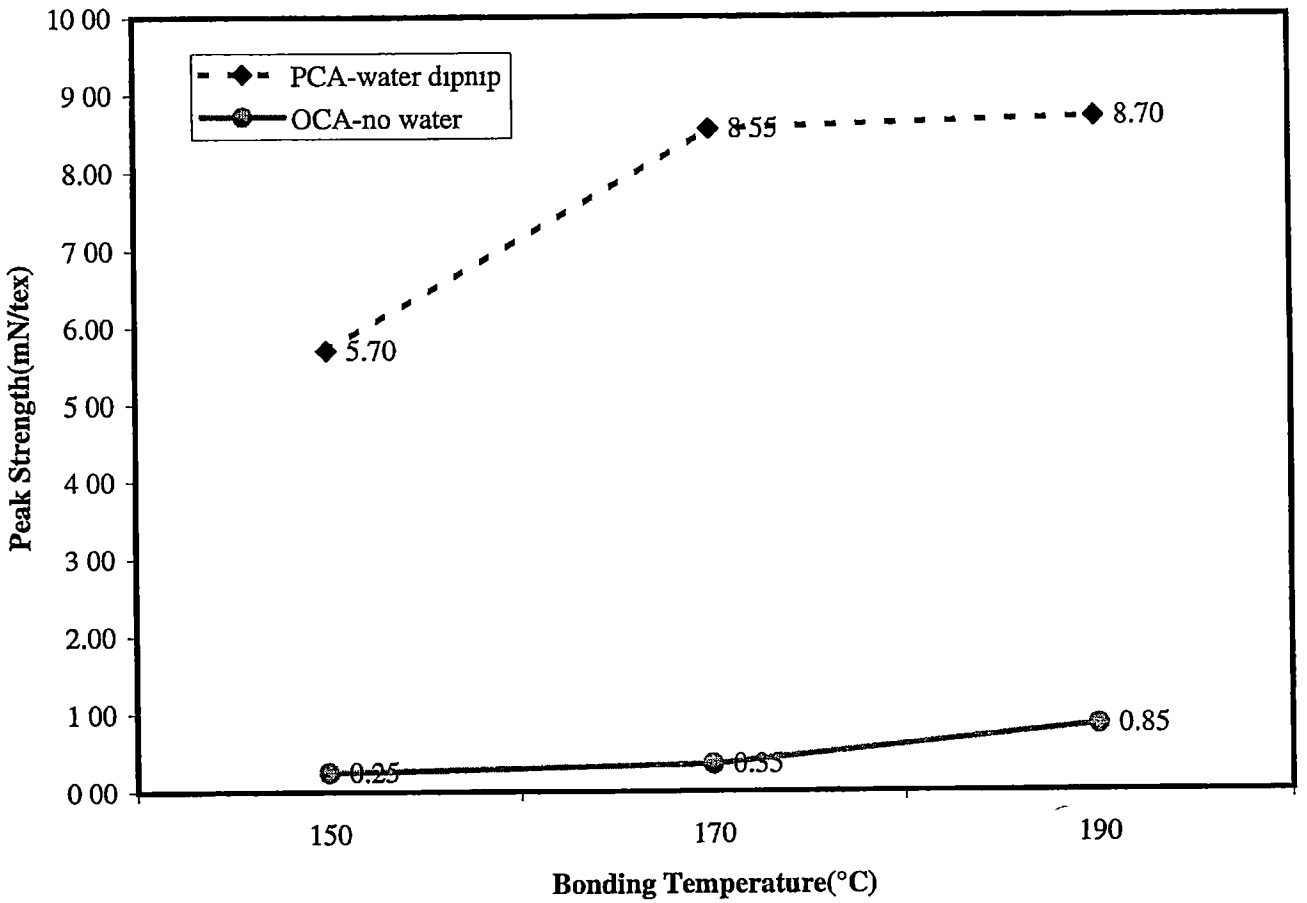


Figure 16 Effect of Combination of Internal and External Plasticizer vs. No Plasticizer on the Peak Strength of C/CA-50/50 Web

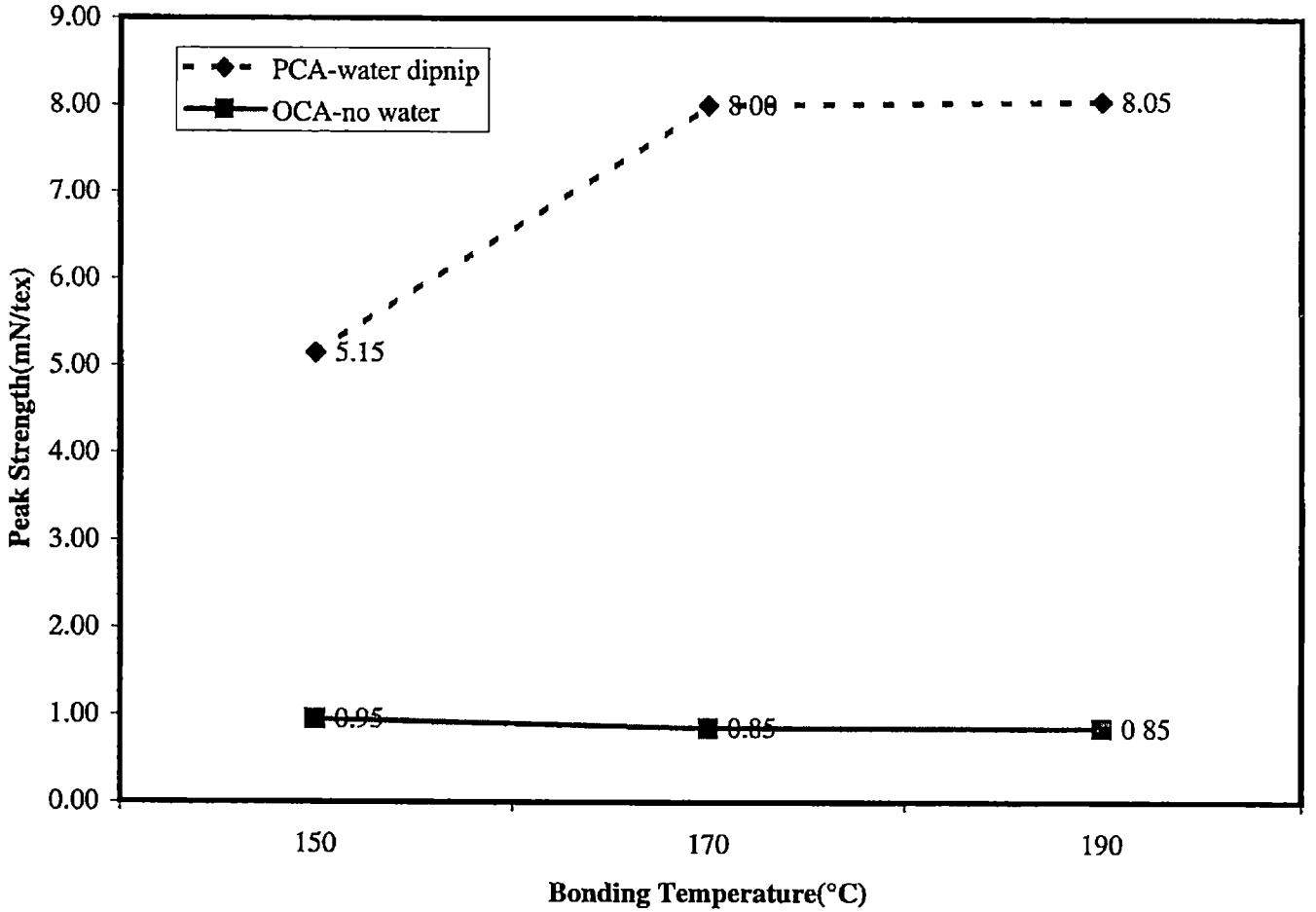


Figure 17 Effect of Combination of Internal and External Plasticizer vs. No Plasticizer on the Peak Strength of C/CA-75/25 Web

Using statistical analysis (Appendix-3), the following hypothesis was tested for each of the six combinations of blend ratio and temperature.

H_0. There is no significant difference in mean peak strength between the use of plasticizing combination treatment and no treatment.

H_1 There is a significant difference in mean peak strength between the use of plasticizing combination treatment and no treatment.

Statistical analysis results are given in Table 8. The combination of internal and external plasticizer effect is compared with C/OCA without any water treatment.

Table 8 Statistical Analysis of Plasticizer Combination Effect on Peak Strength of C/CA Web

Blend Ratio (C/CA)	Temperature (°C)	Peak Strength Difference (PCA with Water Dipnip vs.OCA)	Significance
50/50	150	3 2 mN/tex	*
	170	8 2 mN/tex	*
	190	7 8 mN/tex	*
75/25	150	4 2 mN/tex	*
	170	7 2 mN/tex	*
	190	7 2 mN/tex	*

Note * Accept H_1, and reject H_0, based on $\alpha = 0\ 05$

- Accept H_0, and reject H_1, based on $\alpha = 0\ 05$

The conclusion is that the combination of internal and external plasticizer has a significant effect on improving the peak strength of cotton/cellulose acetate web.

B. PCA with water Dip-nip treatment vs PCA without water dip-nip treatment

To examine the effect of an external plasticizer on webs composed of cotton and internal plasticized cellulose acetate(PCA) fibers, experiments were designed to compare the difference between the combination of internal - external plasticizer and only the internal plasticizer effect The results are shown in Figure 18 and Figure 19

It is seen from the figures that the cotton/plasticized cellulose acetate webs have higher peak strength when treated with an external plasticizer-water than those cotton/plasticized cellulose acetate webs without water dip-nip treatment. The possible exception may be for C/PCA-50/50-190°C webs There is little difference between the two different treatments at the highest bonding temperature.

Using statistical analysis (Appendix-3), the following hypothesis was tested for each of the six combinations of blend ratio and temperature.

H_0: There is no significant difference in mean peak strength between the use of plasticizing combination treatment and no treatment on C/PCA webs

H_1: There is a significant difference in mean peak strength between the use of plasticizing combination treatment and no treatment on C/PCA webs

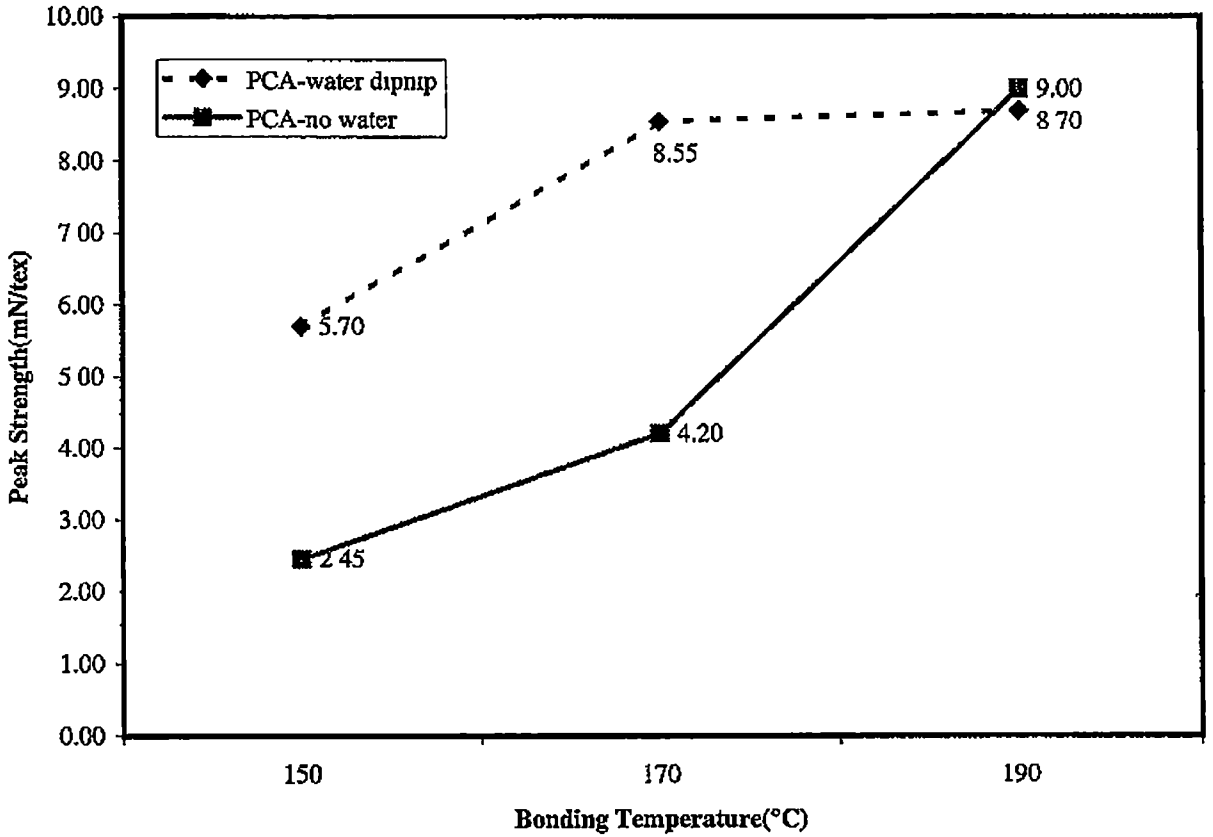


Figure 18 Effect of the Combination of External and Internal Plasticizer vs Internal Plasticizer on the Peak Strength of C/PCA-50/50 Web

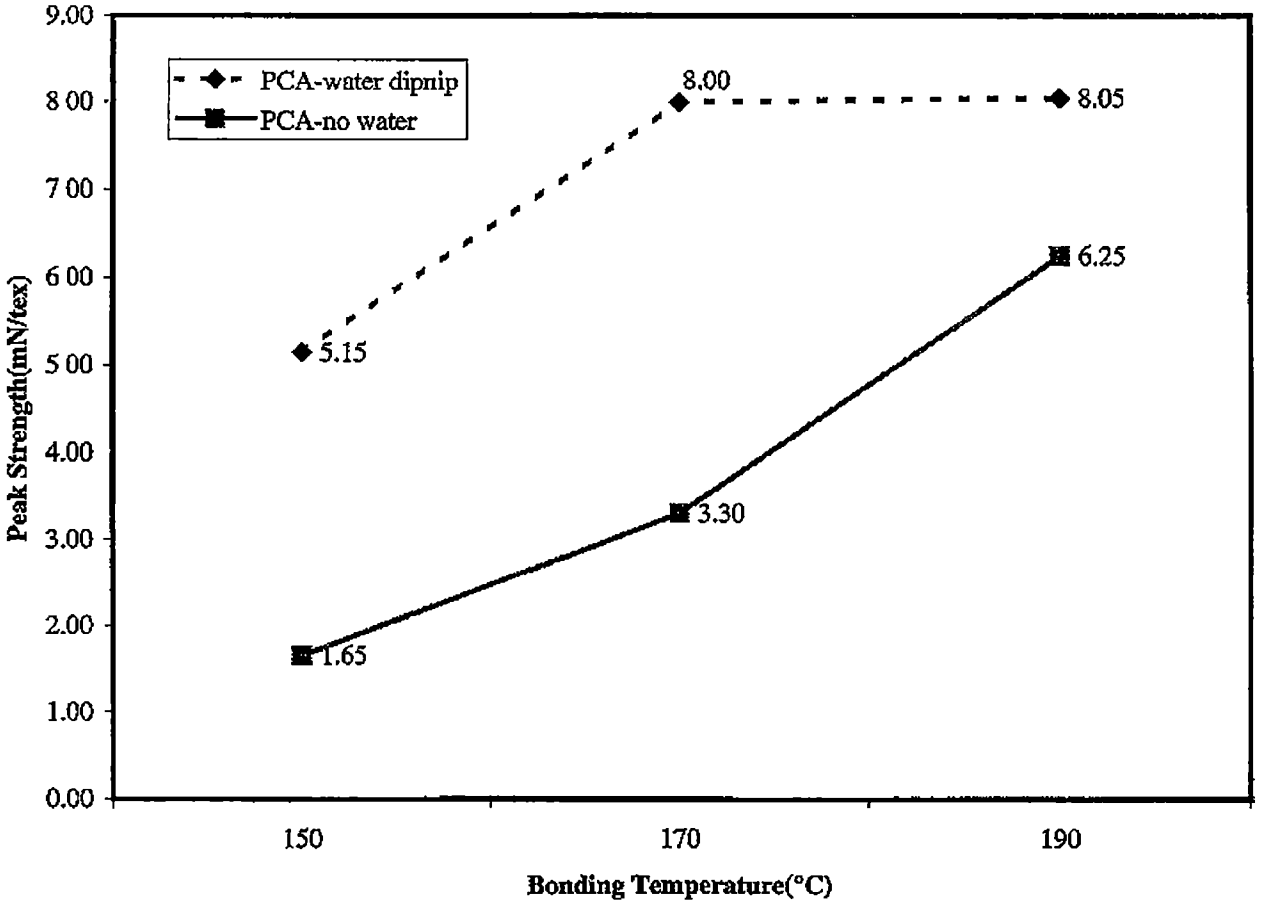


Figure 19 Effect of the Combination of External and Internal Plasticizer vs. Internal Plasticizer on the Peak Strength of C/PCA-75/25 Web

The results are shown in Table 9. The combination of internal and external plasticizer effect is compared with C/PCA without treatment

Table 9 Statistical Analysis of Plasticizer Combination Effect on Peak Strength of C/PCA Web

Blend Ratio (C/PCA)	Temperature (°C)	Peak Strength Difference (Water Dip-nip vs. No water)	Significance
50/50	150	3 2 mN/tex	*
	170	4 4 mN/tex	*
	190	0 3mN/tex	-
75/25	150	3 5 mN/tex	*
	170	4 7 mN/tex	*
	190	1 8 mN/tex	-

Note * Accept H_1, and reject H_0, based on $\alpha = 0\ 05$

- Accept H_0, and reject H_1, based on $\alpha = 0\ 05$

The combination of internal and external plasticizer has a significant effect in lowering the bonding temperature for improved peak strength of cotton/cellulose acetate webs compared to cotton/plasticized cellulose acetate webs However, when the bonding temperature reaches 190°C, the external plasticizer offers no significant benefit to the web strength compared to the internal plasticizer effect alone. The reasoning is that, at lower temperature, the internal plasticizer helps decrease the softening temperature of cellulose acetate by increasing the polymer chain mobility. The interaction between neighboring polymer chains is still very high at low temperature and more polymer chain

flexibility and polymer flow are required for effective bonding. When the external plasticizer - water is introduced into the web, it can decrease the interaction between polymer chains, giving more mobility of the polymer chain, increasing the bonding surface area, and conducting more heat to induce the polymer flow to achieve higher bonding strength.

When the bonding temperature reaches 190 °C, the heat transfer from the calender roll is sufficient for the polymer flow to better bond around the other binder fiber or cotton fiber. If water is applied at this time, the thermal dynamics of water may change considerably More heat may be taken away by evaporation than the heat being conducted by water through the web. In this situation, the water may not be as helpful to web bonding as that at lower temperature. The web peak strength may decrease as a result

4.2 Temperature Effect

The bonding temperature is one of the most important factors that directly affect bonding behavior. For C/OCA webs without a plasticizer treatment, the temperature has no significant effect on web peak strength. Because the temperature in the experimental range has not reached the softening temperature (around 200 °C) of ordinary cellulose acetate, there is limited motion among segments in the polymer chain The mobility of polymer chains is simply not enough to move out of the intermolecularly constrained structure to bond with surrounding fibers.

When the water dip-nip treatment is applied to the C/OCA web, there is no significant difference in the tensile strength in the range of 150 °C and 170 °C The peak strength increases substantially after the bonding temperature reaches 190 °C Water brings down the softening temperature of the cellulose acetate. The higher temperature increases the heat flow into the bonding points, which enhances bonding.

The same trend is observed when there is only internal plasticizer used There is no significant difference in the peak strength of webs between 150 °C and 170 °C When the temperature is increased to 190 °C, the peak strength increases significantly compared with those bonded at 150 °C and 170 °C. Overall, it seems clear that temperature plays a substantial role when there is only one plasticizer applied. Simply stated, the higher the bonding temperature, the stronger the web.

The peak strength does not show a significant increase from 170 °C to 190 °C, when the C/PCA webs have been treated with an external plasticizer The only difference occurs between the webs bonded at 150 °C and the two higher temperatures The conclusion is that the internal and external plasticizer combination can further bring down the softening temperature of cellulose acetate by decreasing the intermolecular forces in the polymer and increasing the mobility of the polymer chain. Good bonding strength can be achieved either by using an internal and external plasticizer combination to bond the web at lower temperature or by using PCA as the binder fiber alone and bonding the web at higher temperature

Again as a side comment, there is no temperature effect on peak elongation for C/PCA webs Only C/OCA web with water pretreatment increases peak elongation significantly with rising temperature The flexural rigidity is increased significantly by using PCA rather than that of OCA at the same temperature. PCA can provide better bonding due to more polymer melt flow than OCA at comparable temperatures, thus increasing the flexural rigidity of the fabric.

4.3 Blend Ratio Effect

The flow of heat into the fiber blend matrix is affected by fiber distribution and blend ratio However, from statistical analysis, there is no significant blend ratio effect on the C/OCA web peak strength when other factors are kept the same.

For C/PCA web bonded at 150 °C and 170 °C, there is a significant blend ratio effect on the peak strength of the web that is treated by the 20% aqueous solution of acetone. The same arguments of explanations are those used for the water effect at lower temperature. At lower temperature, the acetone treatment plays a more important role than does temperature on increasing the polymer chain mobility. This goes along with the larger portion of binder fibers that are available. Polymer chain movement and bonding effects are enhanced

At 190 °C, significant differences in peak strength different are observed for different blend ratios of C/PCA webs when there is no water treatment. The bonding is enhanced with more binder fibers, when the temperature is appropriate.

4.4 Morphology Study on Bonding Points Using SEM

The bonding points were examined using scanning electron microscopy(SEM) to help better explain what morphologies contribute to the tensile strength under different bonding temperatures and plasticizer treatments

4.4.1 Treatment Effect

Bonding points taken from C/PCA-50/50 web were examined and the effect of water treatment on bonding morphology is characterized

From the SEM photos taken on C/PCA-50/50 web bonding area (Figure 20), it is clearly seen that at the same bonding temperature the integrity of bonding points was enhanced with water dip-nip treatment. The edges of the bonding points became much sharper and the fibers became much flatter, thereby increasing the surface contact area and contributing to better bonding. Solvent treatment improves the web bonding structure at lower temperature. The reason is, again, that the softening temperature of cellulose acetate fiber can be reduced with a solvent treatment and the surface tension of cellulose acetate fiber is reduced to make it easier to bond with surrounding fibers.

In Figure 20, A3 and A4 show bonding points taken from C/PCA-50/50 webs bonded at 190 °C These two bonding points show less difference between treatment than those bonded at 150 °C. Both bonds are quite good and clearly visible. The reason for the similarity is that the temperature is already high enough for the CA fiber to stick to the surrounding fibers, irrespective of treatment or no treatment.

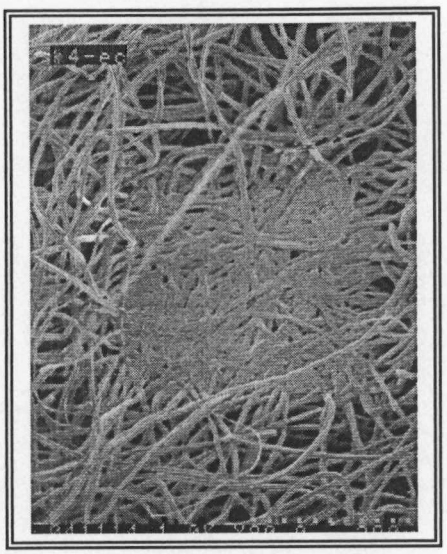
The same conclusion can be drawn from examining the fiber morphology inside the bonding points at higher magnification (Figure 21). The fibers inside the bonding points without treatment look rounder and less altered. However, the fibers inside the bonding points, which have been water pretreated, look much flatter and the edge of the fiber is not very clear. They have been well integrated with surrounding fibers. The fibers became flatter and softer with the water treatment. In the photo taken from acetone treated bonding points, it is difficult to distinguish the fiber inside the bonding point because the acetone treatment has caused part of the cellulose acetate fiber to dissolve, thereby preventing the fiber to remain its integrity The fibers are well bonded together, but help account for why acetone treatment did not surpass water treatment as expected. Some of the binder fibers were dissolved, therefore, the web strength is decreased.

4.4.2 Temperature Effect

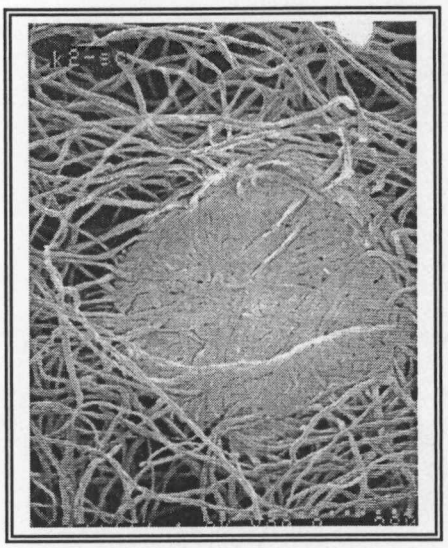
When SEM photos at different temperatures are compared (Figure 20, Figure 22), it is observed that the bonding points become much better defined with temperature increase, and the bonding points look more uniform along the edge It is easier to see the differences caused by the temperature, especially when one compares the photos bonded at 150 °C with those bonded at 190 °C.

4 4 3 Rupture Behavior

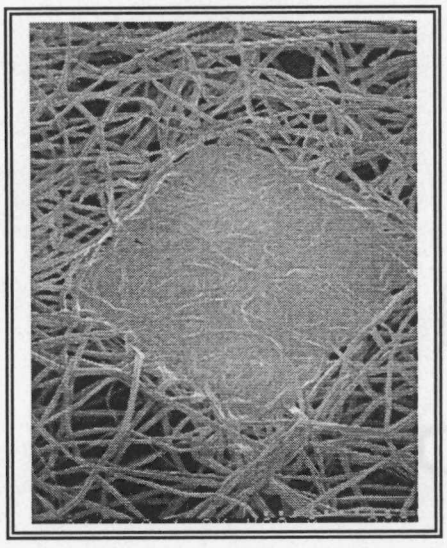
The rupture of bonding points under levels of tensile loading was examined (Figure 23). The mechanism of the bonding rupture is adhesive failure between the fibers within the bonding sites Fibers were peeled from the surface of the bond site or were pulled out of



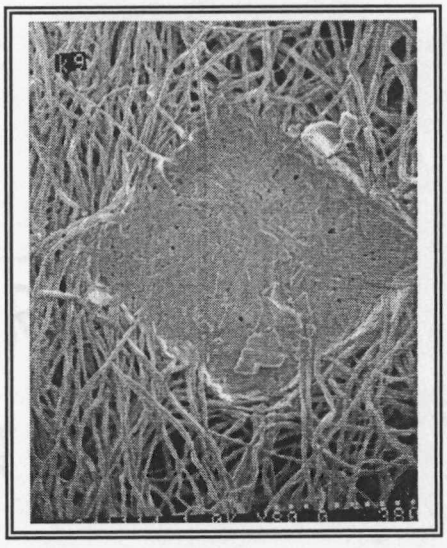
A1-150°C-No Water



A2-150°C-Water Dip-Nip

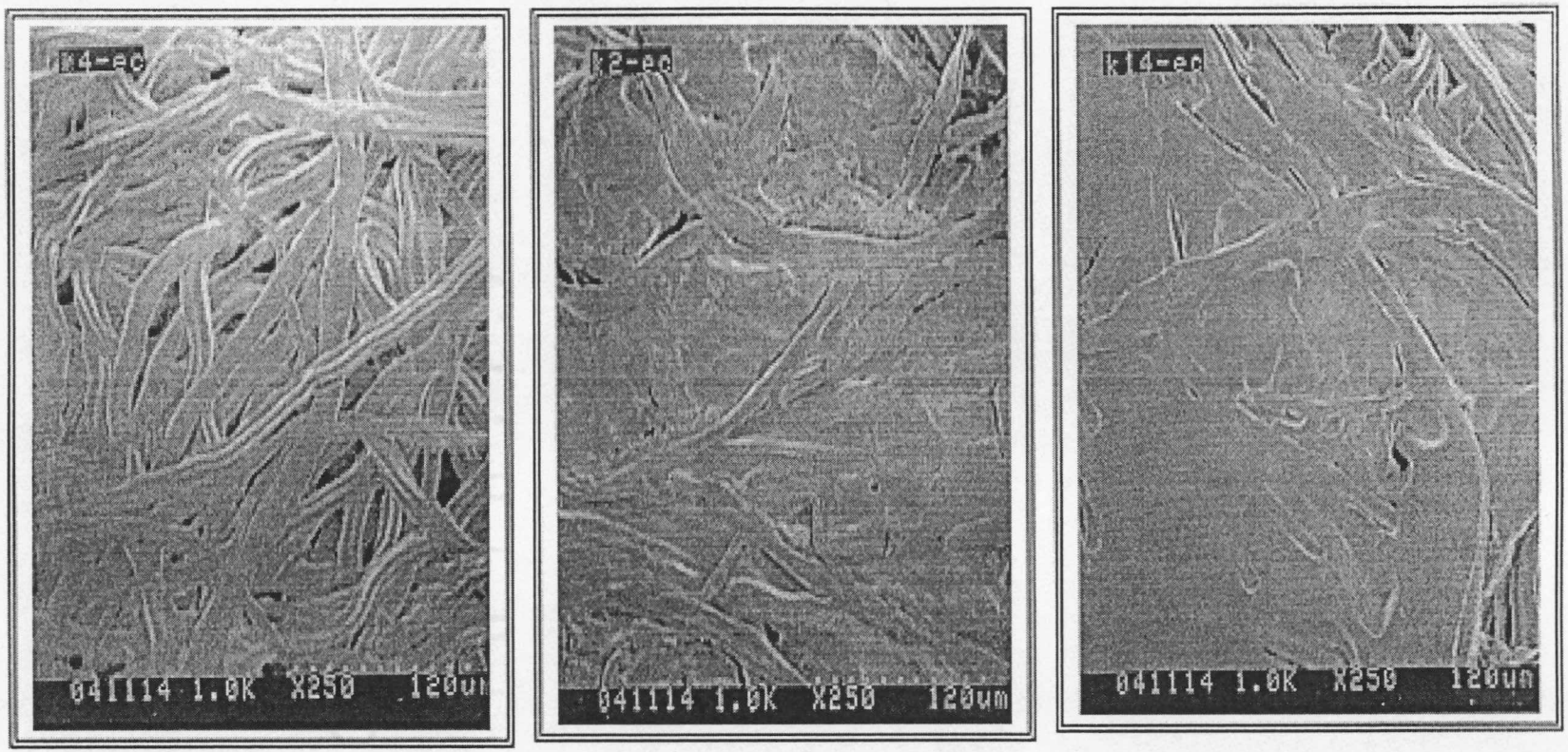


A3-190°C-No Water



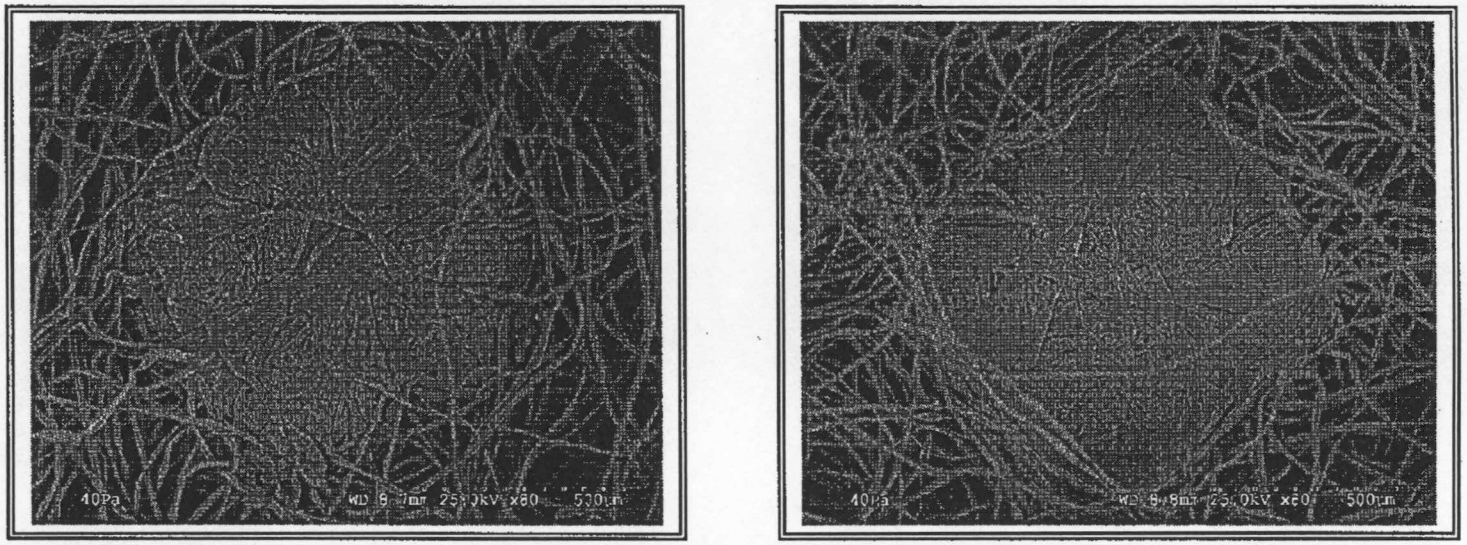
A4-190°C-Water Dip-Nip

Figure 20 Effect of Bonding Temperature and Treatment on Bonding Points from C/PCA-50/50 Webs



No Water | Water Dip-Nip | 20% Acetone Solution

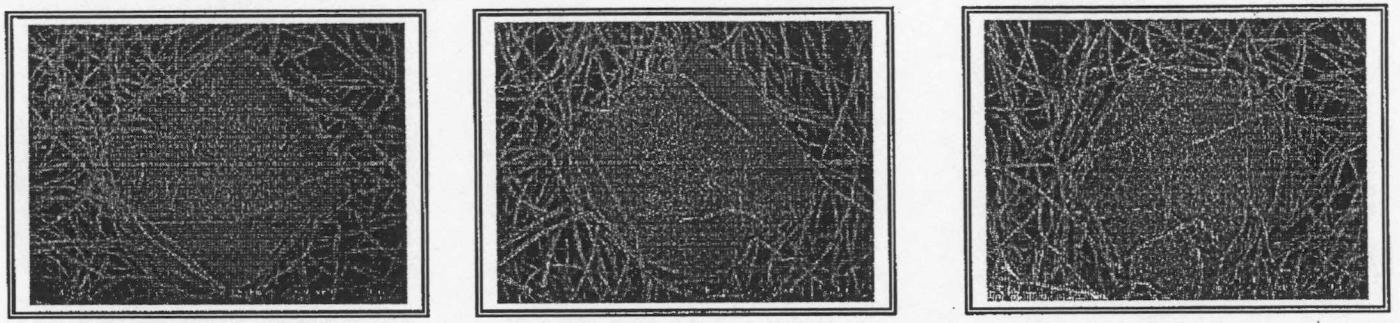
Figure 21 Fiber Morphology of C/PCA-50/50-150°C Webs Bonded Under Different Treatments



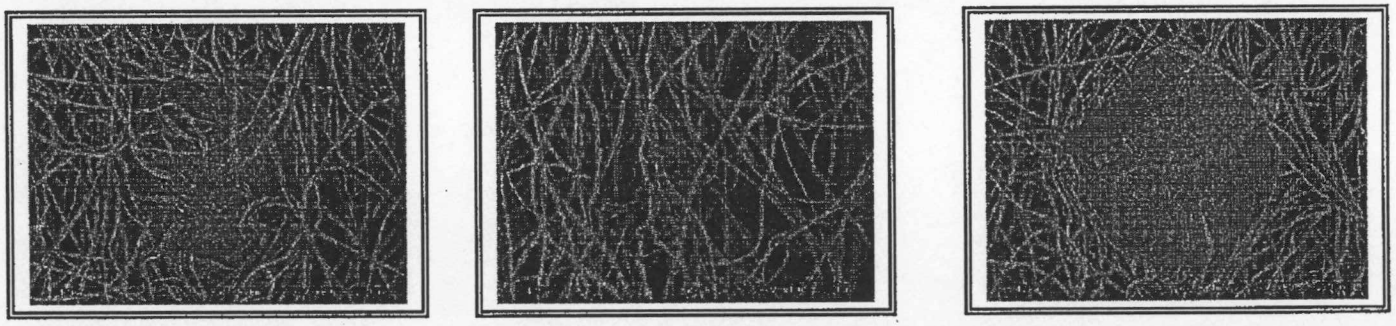
Bonding Temperature = 150°C

Bonding Temperature = 190°C

Figure 22 Temperature Effect on Bonding Points of C/OCA-75/25-Water Spray Webs



No Load | Load Level 1 | Load Level 2



Load Level 3 | Load Level 4 | Load Level 5

Figure 23 SEM Photos of Bonding Rupture on C/OCA-75/25-190°C-Water Spray Webs

the bonding site instead of being broken. The entangled, unbonded fibers were pulled apart. Consequently, nonwoven fabric strengths are largely determined at the embossed bond points rather than by the strength of individual fibers

5 CONCLUSIONS

Several conclusions that are drawn based on this study are

- Water as the external plasticizer, which is applied on the web by dip-nip treatment, can significantly increase the tensile strength of cotton/cellulose acetate thermally bonded webs at reduced calender roll temperatures.

- Water can enhance the cotton/cellulose acetate web bonding to essentially the same degree as an aqueous acetone treatment and provide a good, safe, and more economical choice for industrial manufacture of nonwovens.

- The higher the calender roll temperature, the greater the tensile strength of cotton/cellulose acetate thermally bonded webs.

- Plasticized cellulose acetate as binder fiber provides significantly higher tensile strength to the cotton/cellulose acetate thermally bonded webs than those using ordinary cellulose acetate as binder fiber.

- The use of internal and/or external plasticizer can provide choices of binder fiber and plasticizing treatment for better bonding with acceptable physical properties Two choices are.

    - Cotton/Plasticized Cellulose Acetate-50/50-170°C-water treatment

    - Cotton/Plasticized Cellulose Acetate-50/50-190°C

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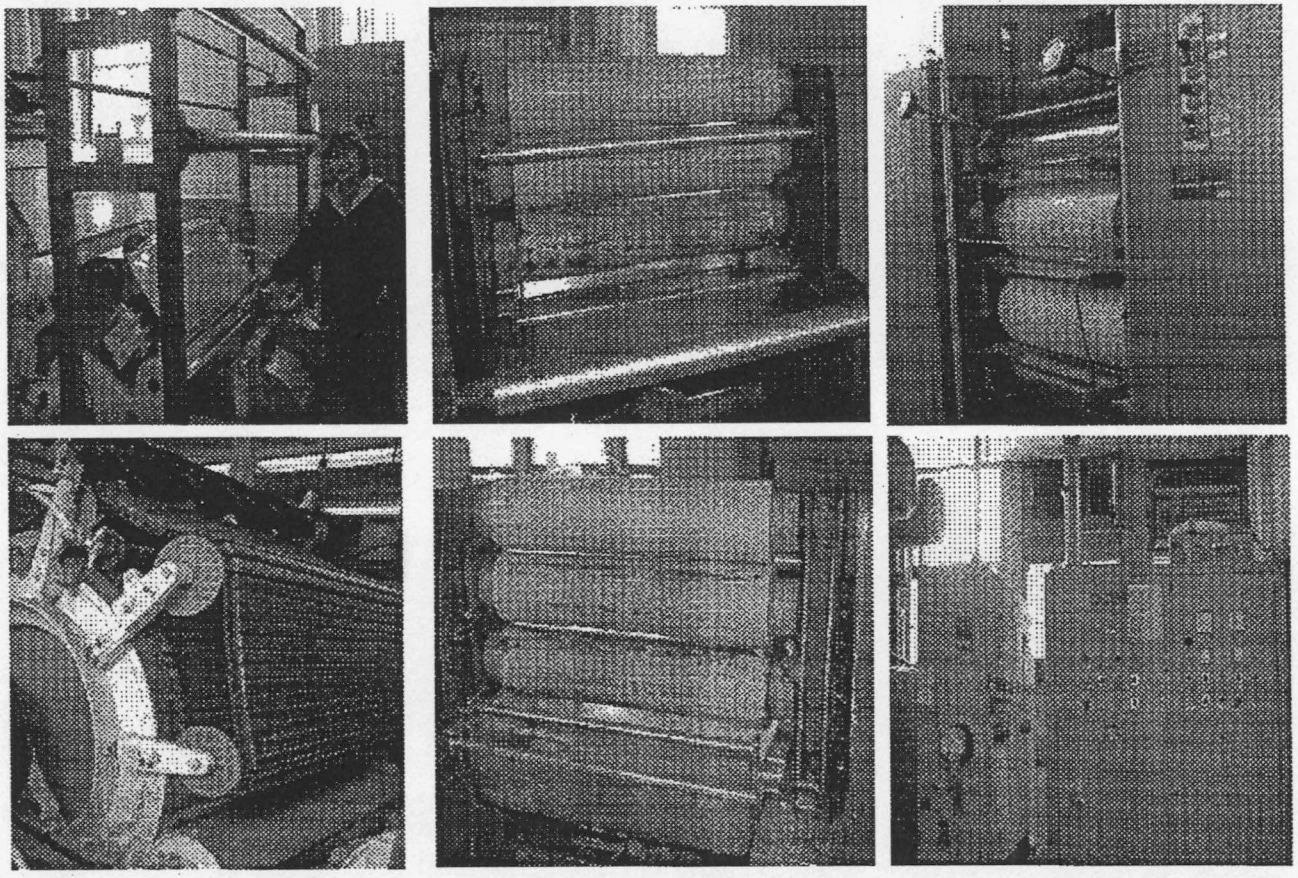
APPENDICES

Appendix-1 Photographs of Machines Being Used in This Research



Carding **Dip-Nip** Calendering

Appendix-2 Programming for Statistical Analysis of Peak Strength

1 *Compare Treatment Effects*

```
UNIANOVA
 peakstre  BY ca temp treatmen blendrat
 /METHOD = SSTYPE(3)
 /INTERCEPT = INCLUDE
 /EMMEANS = TABLES(ca*temp*treatmen*blendrat)
  compare(treatmen)
 /CRITERIA = ALPHA(.05)
 /DESIGN = ca temp treatmen blendrat ca*temp ca*treatmen temp*treatmen ca
*temp*treatmen ca*blendrat temp*blendrat ca*temp*blendrat treatmen*blendrat
 ca*treatmen*blendrat temp*treatmen*blendrat ca*temp*treatmen*blendrat
```

2 *Compare Temperature Effect*

```
UNIANOVA
 peakstre  BY ca temp treatmen blendrat
 /METHOD = SSTYPE(3)
 /INTERCEPT = INCLUDE
 /EMMEANS = TABLES(ca*temp*treatmen*blendrat)
  compare(temp)
 /CRITERIA = ALPHA( 05)
 /DESIGN = ca temp treatmen blendrat ca*temp ca*treatmen temp*treatmen ca
*temp*treatmen ca*blendrat temp*blendrat ca*temp*blendrat treatmen*blendrat
 ca*treatmen*blendrat temp*treatmen*blendrat ca*temp*treatmen*blendrat
```

3. *Compare Blend Ratio Effect*

```
UNIANOVA
 peakstre BY ca temp treatmen blendrat
 /METHOD = SSTYPE(3)
 /INTERCEPT = INCLUDE
 /EMMEANS = TABLES(ca*temp*treatmen*blendrat)
  compare(blendrat)
 /CRITERIA = ALPHA( 05)
 /DESIGN = ca temp treatmen blendrat ca*temp ca*treatmen temp*treatmen ca
*temp*treatmen ca*blendrat temp*blendrat ca*temp*blendrat treatmen*blendrat
 ca*treatmen*blendrat temp*treatmen*blendrat ca*temp*treatmen*blendrat
```

4. *Compare CA Type Effect*

```
UNIANOVA
 peakstre  BY ca temp treatmen blendrat
 /METHOD = SSTYPE(3)
 /INTERCEPT = INCLUDE
 /EMMEANS = TABLES(ca*temp*treatmen*blendrat)
  compare(ca)
 /CRITERIA = ALPHA( 05)
 /DESIGN = ca temp treatmen blendrat ca*temp ca*treatmen temp*treatmen ca
*temp*treatmen ca*blendrat temp*blendrat ca*temp*blendrat treatmen*blendrat

 ca*treatmen*blendrat temp*treatmen*blendrat ca*temp*
```

Appendix-3 Statistical Analysis Results on Peak Strength

Dependent variable: Peak Strength
Factors: CA type, Temperature, Pre-treatment, Blend ratio
GLM – Univariate Analysis of variance

Between-Subjects Factors

		Value Label	N
CA Type	0	OCA	36
	1	PCA	36
Temperature	150		24
	170		24
	190		24
Pre-treatment	0	No water	24
	1	Dip-nip	24
	3	Acetone	24
Blend ratio	0	C/CA=50/50	36
	1	C/CA=75/25	36

Tests of Between-Subjects Effects

Dependent Variable Peak Strength(mN/tex)

Source	Type III Sum of Squares	df	Mean Square	F	Sig
Corrected Model	582 864[a]	35	16 653	18 888	000
Intercept	1575 476	1	1575 476	1786 929	000
CA	153 709	1	153 709	174 339	000
TEMP	171 539	2	85 769	97 281	000
TREATMEN	163 175	2	81 588	92 538	000
BLENDRAT	9 680	1	9 680	10 979	002
CA * TEMP	3 742	2	1 871	2 122	135
CA * TREATMEN	7 089	2	3 544	4 020	027
TEMP * TREATMEN	6 606	4	1 651	1 873	136
CA * TEMP * TREATMEN	43 111	4	10 778	12 224	000
CA * BLENDRAT	8 820	1	8 820	10 004	003
TEMP * BLENDRAT	726	2	363	412	666
CA * TEMP * BLENDRAT	543	2	271	308	737
TREATMEN * BLENDRAT	2 456	2	1 228	1 393	261
CA * TREATMEN * BLENDRAT	2 486	2	1 243	1 410	257
TEMP * TREATMEN * BLENDRAT	6 738	4	1 685	1 911	130
CA * TEMP * TREATMEN * BLENDRAT	2 447	4	612	694	601
Error	31 740	36	882		
Total	2190 080	72			
Corrected Total	614 604	71			

a R Squared = 948 (Adjusted R Squared = 898)

- **Treatment Comparisons**

Pairwise Comparisons

Dependent Variable Peak Strength(mN/tex)

CA Type	Temperature	Blend ratio	(I) Pre-treatment	(J) Pre treatment	Mean Difference (I-J)	Std Error	Sig [a]
OCA	150	C/CA=50/50	No water	Dip nip	-2 250*	939	022
				Acetone	-1 750	939	071
			Dip-nip	No water	2 250*	939	022
				Acetone	500	939	598
			Acetone	No water	1 750	939	071
				Dip-nip	- 500	939	598
		C/CA=75/25	No water	Dip-nip	-1 100	939	249
				Acetone	-1 150	939	229
			Dip-nip	No water	1 100	939	249
				Acetone	5 000E 02	939	958
			Acetone	No water	1 150	939	229
				Dip-nip	5 000E 02	939	958
	170	C/CA=50/50	No water	Dip-nip	4 000	939	000
				Acetone	4 350	939	000
			Dip-nip	No water	4 000	939	000
				Acetone	- 350	939	712
			Acetone	No water	4 350*	939	000
				Dip-nip	350	939	712
		C/CA=75/25	No water	Dip nip	-2 800	939	005
				Acetone	2 500	939	012
			Dip nip	No water	2 800*	939	005
				Acetone	300	939	751
			Acetone	No water	2 500*	939	012
				Dip-nip	- 300	939	751
	190	C/CA=50/50	No water	Dip-nip	6 800	939	000
				Acetone	5 600*	939	000
			Dip-nip	No water	6 800*	939	000
				Acetone	1 200	939	209
			Acetone	No water	5 600*	939	000
				Dip-nip	-1 200	939	209
		C/CA=75/25	No water	Dip-nip	-7 250*	939	000
				Acetone	-6 050*	939	000
			Dip-nip	No water	7 250*	939	000
				Acetone	1 200	939	209
			Acetone	No water	6 050*	939	000
				Dip-nip	1 200	939	209
PCA	150	C/CA=50/50	No water	Dip nip	3 250*	939	001
				Acetone	-3 800*	939	000
			Dip-nip	No water	3 250*	939	001
				Acetone	550	939	562
			Acetone	No water	3 800	939	000
				Dip-nip	550	939	562
		C/CA=75/25	No water	Dip-nip	3 500*	939	001
				Acetone	-1 150	939	229
			Dip-nip	No water	3 500*	939	001
				Acetone	2 350*	939	017
			Acetone	No water	1 150	939	229
				Dip-nip	2 350*	939	017
	170	C/CA=50/50	No water	Dip nip	4 350*	939	000
				Acetone	-4 250*	939	000
			Dip-nip	No water	4 350*	939	000
				Acetone	100	939	916
			Acetone	No water	4 250*	939	000
				Dip-nip	100	939	916
		C/CA=75/25	No water	Dip-nip	4 700	939	000
				Acetone	2 300*	939	019
			Dip-nip	No water	4 700*	939	000
				Acetone	2 400*	939	015
			Acetone	No water	2 300*	939	019
				Dip-nip	2 400*	939	015
	190	C/CA=50/50	No water	Dip-nip	300	939	751
				Acetone	600	939	527
			Dip-nip	No water	300	939	751
				Acetone	300	939	751
			Acetone	No water	600	939	527
				Dip nip	300	939	751
		C/CA=75/25	No water	Dip nip	1 800	939	063
				Acetone	1 750	939	071
			Dip-nip	No water	1 800	939	063
				Acetone	5 000E 02	939	958
			Acetone	No water	1 750	939	071
				Dip-nip	5 000E 02	939	958

Based on estimated marginal means

* The mean difference is significant at the 05 level

[a] Adjustment for multiple comparisons Least Significant Difference (equivalent to no adjustments)

- **Temperature Comparisons**

Pairwise Comparisons

Dependent Variable Peak Strength(mN/tex)

CA Type	Pre treatment	Blend ratio	(I) Temperature	(J) Temperature	Mean Difference (I-J)	Std Error	Sig [a]
OCA	No water	C/CA=50/50	150	170	1 000E-01	939	916
				190	- 600	939	527
			170	150	1 000E-01	939	916
				190	- 500	939	598
			190	150	600	939	527
				170	500	939	598
		C/CA=75/25	150	170	100	939	916
				190	100	939	916
			170	150	- 100	939	916
				190	1 155E 14	939	1 000
			190	150	- 100	939	916
				170	1 155E-14	939	1 000
	Dip nip	C/CA=50/50	150	170	1 850	939	057
				190	5 150	939	000
			170	150	1 850	939	057
				190	-3 300*	939	001
			190	150	5 150	939	000
				170	3 300	939	001
		C/CA=75/25	150	170	1 600	939	097
				190	-6 050	939	000
			170	150	1 600	939	097
				190	-4 450	939	000
			190	150	6 050	939	000
				170	4 450	939	000
	Acetone	C/CA=50/50	150	170	2 700	939	007
				190	-4 450	939	000
			170	150	2 700	939	007
				190	-1 750	939	071
			190	150	4 450	939	000
				170	1 750	939	071
		C/CA=75/25	150	170	1 250	939	191
				190	-4 800	939	000
			170	150	1 250	939	191
				190	-3 550	939	001
			190	150	4 800	939	000
				170	3 550	939	001
PCA	No water	C/CA=50/50	150	170	-1 750	939	071
				190	-6 550	939	000
			170	150	1 750	939	071
				190	-4 800*	939	000
			190	150	6 550	939	000
				170	4 800*	939	000
		C/CA=75/25	150	170	1 650	939	087
				190	-4 600	939	000
			170	150	1 650	939	087
				190	2 950*	939	003
			190	150	4 600	939	000
				170	2 950	939	003
	Dip-nip	C/CA=50/50	150	170	2 850	939	004
				190	-3 000	939	003
			170	150	2 850	939	004
				190	150	939	874
			190	150	3 000	939	003
				170	150	939	874
		C/CA=75/25	150	170	2 850	939	004
				190	2 900	939	004
			170	150	2 850	939	004
				190	5 000E-02	939	958
			190	150	2 900*	939	004
				170	5 000E-02	939	958
	Acetone	C/CA=50/50	150	170	2 200	939	025
				190	2 150	939	028
			170	150	2 200	939	025
				190	5 000E-02	939	958
			190	150	2 150	939	028
				170	5 000E-02	939	958
		C/CA=75/25	150	170	-2 800	939	005
				190	5 200	939	000
			170	150	2 800	939	005
				190	2 400	939	015
			190	150	5 200	939	000
				170	2 400	939	015

Based on estimated marginal means

The mean difference is significant at the 05 level

a Adjustment for multiple comparisons Least Significant Difference (equivalent to no adjustments)

- **Blend Ratio Comparisons**

Pairwise Comparisons

Dependent Variable Peak Strength(mN/tex)

CA Type	Temperature	Pre-treatment	(I) Blend ratio	(J) Blend ratio	Mean Difference (I-J)	Std Error	Sig [a]
OCA	150	No water	C/CA=50/50	C/CA=75/25	- 700	939	461
			C/CA=75/25	C/CA=50/50	700	939	461
		Dip-nip	C/CA=50/50	C/CA=75/25	450	939	635
			C/CA=75/25	C/CA=50/50	- 450	939	635
		Acetone	C/CA=50/50	C/CA=75/25	-1 000E-01	939	916
			C/CA=75/25	C/CA=50/50	1 000E-01	939	916
	170	No water	C/CA=50/50	C/CA=75/25	- 500	939	598
			C/CA=75/25	C/CA=50/50	500	939	598
		Dip-nip	C/CA=50/50	C/CA=75/25	700	939	461
			C/CA=75/25	C/CA=50/50	- 700	939	461
		Acetone	C/CA=50/50	C/CA=75/25	1 350	939	159
			C/CA=75/25	C/CA=50/50	-1 350	939	159
	190	No water	C/CA=50/50	C/CA=75/25	7 994E-15	939	1 000
			C/CA=75/25	C/CA=50/50	-7 994E-15	939	1 000
		Dip-nip	C/CA=50/50	C/CA=75/25	- 450	939	635
			C/CA=75/25	C/CA=50/50	450	939	635
		Acetone	C/CA=50/50	C/CA=75/25	- 450	939	635
			C/CA=75/25	C/CA=50/50	450	939	635
PCA	150	No water	C/CA=50/50	C/CA=75/25	800	939	400
			C/CA=75/25	C/CA=50/50	- 800	939	400
		Dip-nip	C/CA=50/50	C/CA=75/25	550	939	562
			C/CA=75/25	C/CA=50/50	- 550	939	562
		Acetone	C/CA=50/50	C/CA=75/25	3 450*	939	001
			C/CA=75/25	C/CA=50/50	-3 450*	939	001
	170	No water	C/CA=50/50	C/CA=75/25	900	939	344
			C/CA=75/25	C/CA=50/50	- 900	939	344
		Dip-nip	C/CA=50/50	C/CA=75/25	550	939	562
			C/CA=75/25	C/CA=50/50	- 550	939	562
		Acetone	C/CA=50/50	C/CA=75/25	2 850*	939	004
			C/CA=75/25	C/CA=50/50	-2 850*	939	004
	190	No water	C/CA=50/50	C/CA=75/25	2 750*	939	006
			C/CA=75/25	C/CA=50/50	-2 750*	939	006
		Dip-nip	C/CA=50/50	C/CA=75/25	650	939	493
			C/CA=75/25	C/CA=50/50	- 650	939	493
		Acetone	C/CA=50/50	C/CA=75/25	400	939	673
			C/CA=75/25	C/CA=50/50	- 400	939	673

Based on estimated marginal means

* The mean difference is significant at the 05 level

[a] Adjustment for multiple comparisons Least Significant Difference (equivalent to no adjustments)

- **CA Type Comparisons**

Pairwise Comparisons

Dependent Variable Peak Strength(mN/tex)

Temperature	Pre-treatment	Blend ratio	(I) CA Type	(J) CA Type	Mean Difference (I-J)	Std Error	Sig[a]
150	No water	C/CA=50/50	OCA	PCA	-2 200*	939	025
			PCA	OCA	2 200*	939	025
		C/CA=75/25	OCA	PCA	- 700	939	461
			PCA	OCA	700	939	461
	Dip-nip	C/CA=50/50	OCA	PCA	-3 200*	939	002
			PCA	OCA	3 200*	939	002
		C/CA=75/25	OCA	PCA	-3 100*	939	002
			PCA	OCA	3 100*	939	002
	Acetone	C/CA=50/50	OCA	PCA	-4 250*	939	000
			PCA	OCA	4 250*	939	000
		C/CA=75/25	OCA	PCA	- 700	939	461
			PCA	OCA	700	939	461
170	No water	C/CA=50/50	OCA	PCA	-3 850*	939	000
			PCA	OCA	3 850*	939	000
		C/CA=75/25	OCA	PCA	-2 450*	939	013
			PCA	OCA	2 450*	939	013
	Dip-nip	C/CA=50/50	OCA	PCA	-4 200*	939	000
			PCA	OCA	4 200*	939	000
		C/CA=75/25	OCA	PCA	-4 350*	939	000
			PCA	OCA	4 350*	939	000
	Acetone	C/CA=50/50	OCA	PCA	-3 750*	939	000
			PCA	OCA	3 750*	939	000
		C/CA=75/25	OCA	PCA	-2 250*	939	022
			PCA	OCA	2 250*	939	022
190	No water	C/CA=50/50	OCA	PCA	-8 150*	939	000
			PCA	OCA	8 150*	939	000
		C/CA=75/25	OCA	PCA	-5 400*	939	000
			PCA	OCA	5 400*	939	000
	Dip-nip	C/CA=50/50	OCA	PCA	-1 050	939	271
			PCA	OCA	1 050	939	271
		C/CA=75/25	OCA	PCA	5 000E-02	939	958
			PCA	OCA	-5 000E-02	939	958
	Acetone	C/CA=50/50	OCA	PCA	-1 950*	939	045
			PCA	OCA	1 950*	939	045
		C/CA=75/25	OCA	PCA	-1 100	939	249
			PCA	OCA	1 100	939	249

Based on estimated marginal means

* The mean difference is significant at the 05 level

[a] Adjustment for multiple comparisons Least Significant Difference (equivalent to no adjustments)

VITA

Xiao Gao was born in HeilongJiang Province, P R China, on November 07,1972. She joined Beijing University of Chemical Technology (BUCT) in September 1990 and received her Bachelor of Polymer Engineering Degree in July 1994 She continued her study in BUCT and achieved the Master Degree in polymer engineering in 1997. After one year's working, she came to University of Tennessee in 1998 and spent half year in chemistry department doing organic synthesis In Spring, 1999 she was so attracted by the industry processing and joined the Master's program in Textile Science at the University of Tennessee, Knoxville, where she received her degree in August 1999. She was employed as Graduate Research Assistant in the department of Textile Science during her stay at the University of Tennessee Her research interests are in polymer processing and nonwoven product design