TEKSTİL VE MÜHENDİS

(Journal of Textiles and Engineer)

http://www.tekstilvemuhendis.org.tr

A Research on Tensile Properties of Nonwoven Fabrics Produced from Staple Polyester and Sheath/Core Low Melting Staple Polyester Binder Fibres with Carding, Needle Punching and Pressing Machines

Kesikli Poliester ve Dış/İç Düşük Sıcaklıkta Eriyen Kesikli Poliester Bağlayıcı Liflerinden Tarak, İğneleme ve Pres Makineleri ile Üretilmiş Dokunmamış Kumaşların Mukavemet Özellikleri Üzerine Bir Araştırma

Mustafa Sabri ÖZEN
T.C. Marmara University, Textile Engineering Department, Kadıköy, Istanbul, Turkey

Bu makaleye atıf yapmak için (To cite this article):

Mustafa Sabri ÖZEN (2017): A Research on Tensile Properties of Nonwoven Fabrics Produced from Staple Polyester and Sheath/Core Low Melting Staple Polyester Binder Fibres with Carding, Needle Punching and Pressing Machines**,** Tekstil ve Mühendis, 24: 108, 233-242.

For online version of the article: https://doi.org/10.7216/1300759920172410802

TMMOB Tekstil Mühendisleri Odası
UCTEA Chamber of Textile Engineers
Tekstil ve Mühendis
Journal of Textiles and Engineer

Yıl (Year) : 2017/3
Cilt (Vol) : 24
Sayı (No) : 108

Araştırma Makalesi / Research Article

A RESEARCH ON TENSILE PROPERTIES OF NONWOVEN FABRICS PRODUCED FROM STAPLE POLYESTER AND SHEATH/CORE LOW MELTING STAPLE POLYESTER BINDER FIBRES WITH CARDING, NEEDLE PUNCHING AND PRESSING MACHINES

Mustafa Sabri ÖZEN

T.C. Marmara University, Textile Engineering Department, Kadıköy, Istanbul, Turkey

Received / Gönderilme Tarihi: 28.06.2017
Accepted / Kabul Tarihi: 15.12.2017

ABSTRACT: In this study, nonwoven fabrics were produced from staple polyester fibres and sheath/core low melting staple polyester binder fibres at different blending ratios by carding processes and then post-bonding processes such as needle punching and thermal bonding with pressing. The effect of sheath/core low melting polyester binder fibre ratio on tensile properties of needle punched and thermally bonded nonwoven fabrics was investigated. Sheath/core low melting staple polyester binder fibres were blended with staple polyester fibres at the ratios 5%, 10%, 20%, 30%, 40% and 50%. Webs were formed at carding machine and then bonded mechanically and thermally at needle punching and pressing machines. Fabric area density, thickness, fabric tenacity and elongation at break properties of the produced needle punched and thermally bonded nonwoven fabrics were tested according to ISO and ASTM standards. Experimental results clearly revealed that tenacity values of needle punched and thermally bonded nonwoven fabrics increased with increasing of sheath/core low melting polyester binder fibre ratio. It was observed that as the 30% and higher low melting polyester binder fibre ratios were used, the tenacity values of needle punched and thermally bonded nonwoven fabrics dramatically increased both machine and cross direction. It was found that needle punched and thermally bonded nonwoven fabric thickness values decreased with increasing of sheath/core low melting staple polyester binder fibre ratio.

Keywords: Nonwoven fabric, needle-punching, sheath/core low melting staple polyester binder fibre, thermal bonding.

KESİKLİ POLİESTER VE DIŞ/İÇ DÜŞÜK SICAKLIKTA ERİYEN KESİKLİ POLİESTER BAĞLAYICI LİFLERİNDEN TARAK, İĞNELEME VE PRES MAKİNELERİ İLE ÜRETİLMİŞ DOKUNMAMIŞ KUMAŞLARIN MUKAVEMET ÖZELLİKLERİ ÜZERİNE BİR ARAŞTIRMA

ÖZET: Bu çalışmada, kesikli poliester liflerinden ve dış/iç düşük sıcaklıkta eriyen kesikli bağlayıcı poliester liflerinden, farklı karışım oranlarında, tarak prosesi ve sonrasında iğneleme ve sıcak pres ile ısı ile bağlama yapılarak dokunmamış kumaşlar üretilmiştir. İğnelenmiş ve ısı ile bağlanmış dokunmamış kumaşların mukavemet özelliklerinde dış/iç düşük sıcaklıkta eriyen bağlayıcı poliester liflerin etkisi araştırılmıştır. Dış/iç düşük sıcaklıkta eriyen bağlayıcı poliester lifleri %5, %10, %20, %30, %40 ve %50 oranlarında kesikli poliester lifleri ile karıştırılmıştır. Tülbent dokular tarak makinesinde oluşturulmuş ve sonrasında iğneleme ve pres makinelerinde mekanik ve ısıl yöntemlerle bağlanmıştır. Üretilen iğnelenmiş ve ısı ile bağlanmış dokunmamış kumaşların birim metre kare ağırlığı, kalınlık, mukavemet ve kopma anında uzama özellikleri ISO ve ASTM standartlarına göre test edilmiştir. Deneysel sonuçlar çok açık bir şekilde, dış/iç düşük sıcaklıkta eriyen poliester bağlayıcı lif oranının artmasıyla, iğnelenmiş ve ısı ile bağlanmış dokunmamış kumaş mukavemetinin arttığını göstermiştir. %30 ve daha fazla oranda dış/iç düşük sıcaklıkta eriyen poliester bağlayıcı elyaf kullanıldığında, iğnelenmiş ve ısı ile bağlanmış dokunmamış kumaş mukavemetinin hem makine hem de makine yönüne dik yönde önemli oranda arttığı gözlenmiştir. Dış/iç düşük sıcaklıkta eriyen poliester bağlayıcı lif oranının artmasıyla, iğnelenmiş ve ısı ile bağlanmış dokunmamış kumaşların kalınlık değerlerinin de azaldığı tespit edilmiştir.

Anahtar Kelimeler: Dokunmamış kumaş, iğneleme, dış/iç düşük sıcaklıkta eriyen kesikli poliester bağlayıcı lifler, ısı ile bağlama.

**** Sorumlu Yazar/Corresponding Author:*** *mustafaozen@marmara.edu.tr*
DOI: *10.7216/1300759920172410802, www.tekstilvemuhendis.org.tr*

1. INTRODUCTION

The rising cost of energy and greater awareness of the environmental impact of latex bonding led to a change in direction. As a result of this, the usage of thermal bonding instead of chemical bonding has increased. The high production rates possible with thermal bonding and the significant energy savings as compared to chemical bonding, due to the absence of significant water evaporation during bonding, makes the process economically attractive. In this method, bicomponent and low melting fibres as a binder material can be used [1].

Sheath/core bicomponent fibre and sheath/core low melting fibre are the most widely used and the most well-known binder fibres. Such fibres have a sheath/core structure with outer layer having a lower melting temperature that that of the core part. When the fibre is heated, the sheath part of the fibre melts. These kinds of fibres are blended and mixed with carrier fibres at specific blending ratios. Bicomponent and low melting sheath/core staple fibres have specific sheath/core ratio. In this study, sheath/core low melting staple polyester binder fibres with 50/50% by weight were used.

Bicomponent and sheath/core low melting fibres are made from two components distributed over the entire length of the fibre. They may either belong to the same type of polymer or be totally different polymer types. PET/low melting PET is the low melting polyester fibre consisting of same type of polymer.

Low melting polyester staple fibre is used as binder (a bonding agent) to combine staple fibres using heat in the manufacturing process of nonwoven fabric, and it is mainly used in nonwoven fabric used for acoustic insulation material for automotive, acquisition distribution layer (ADL) and cushions for mattress and other furniture. Low melting (LM) polyester staple fibre is the eco-friendly material used in thermo-bonding and its global market is expanding at a rate of 8% per year [2].

Polyethylene/polypropylene (PE/PP) is the bicomponent fibre consisting of different polymer types. By co-extruding two polymers into one single fibre, the different properties of both polymers are combined. Bicomponent fibres are classified according to the distribution of each component within cross-sectional area. Typical cross-section configurations include side-by-side, eccentric, core-sheath, islands-in-the-sea and segmented-pie [3].

Wool type carding machine is the most used machine for web forming from staple bicomponent or low melting binder fibres at nonwoven industry. Carding is defined that a process for making fibrous webs in which the fibres are aligned either parallel or randomly to each other. The fibrous web produced at the end of the carding machine is wound on a drum or folded by a cross lapper. In the experimental study, Mesdan laboratory type sample carding machine was used for making webs [4, 5].

Webs can be bonded with mechanical, thermal or chemical bonding technologies and machines. In our study, needle punching machine was used. Needle punching is a process of bonding nonwoven web structures by mechanically interlocking the fibres through the web. Barbed felting needles mounted on a board, punch fibres into the web and then withdraw leaving the fibres entangled. By varying the stroke per minute, the advance rate of the web, and the degree of penetration of the needles, a wide range of fabric densities can be achieved [4, 5]. Thermally bonding, also known as “heat bonding” or “melt bonding” is a process of using heat to bond or stabilize a web structure that consists of a thermoplastic fibre. In the process, heat and pressure are applied and the web is melted at fibre crossover points [6].

The basic concept of thermally bonding was introduced by Reed in 1942 [7]. The process is relatively simple. There are mostly used two kind of thermally bonding methods. One of them is bonding with calendar cylinders. Another method is through-air ovens. Hot calendaring and hot oven are the most frequently methods used for thermally bonding of nonwoven webs and fabrics [4, 5]. Thermal bonding is successfully employed in bonding of dry-laid, spun-laid and wet-laid webs [7].

Thermal bonding is increasingly used at the expense of chemical bonding for a number of reasons. Thermal bonding can be run at high speed, whereas the speed of chemical bonding is limited by the drying and curing stage [8, 9].

Thermal bonding requires a thermoplastic component to be present in the form of a fibre, film, powder or as a sheath part of a bicomponent or low melting fibre. The heat is applied until the thermoplastic component becomes viscous or melts [10]. Polyethylene powders, PET/co-PET, PE/PP sheath/core bicomponent fibres are mostly used at thermal bonding industry in the world.

Mechanical or tensile properties of needle punched and thermal bonded nonwoven fabrics depend on the fibre properties, web characteristics, web forming and web bonding machine parameters and variables. Mechanical and tensile properties of nonwoven fabrics depend on fibre structural characteristics such as fineness, length and curl. The arrangement of the fibres and their orientation distribution are related to the mechanical structure of the web. Fibre orientation has a big influence on the tensile strength of the nonwoven material. An uneven distribution in fibre orientation results in anisotropic behaviours in mechanical properties [11]. Web characteristics affecting the properties of needle punched and thermal bonded nonwoven fabric include fabric area density, fibre orientation in the web and web composition. There are direct relationship between fabric area density and mechanical properties of the nonwoven fabric [12]. The needling operation parameters such as punch density per cm^2, needle penetration depth (mm) and type of needle affect the resultant nonwoven fabric both physically and mechanically [13]. The increase in punching density generally improves the mechanical properties of nonwoven fabrics through increased entanglement. However, excessive needle punching results in breaking of fibres and spreading of fabric. Thus, the needle punched nonwoven fabric has an optimum punching density [14]. Anandjiwala and Boguslavsky [15] remarked that an increased depth of needle penetration resulted in deeper interlocking and entanglement of fibres and thus higher compaction; although when the depth of needle penetration was too deep it could lead to negative effects such as fibre breakage

[16]. In thermal bonding, cylinder or through-air temperature, pressure and processing speed employed play a decisive role on the mechanical properties of nonwoven fabric [17]. It is generally observed that the strength of the structure improves with bonding temperature, reaches a maximum, and then declines rapidly because of over-bonding and premature failure of the fiber-bond interface [18]. Bahari et al. found that calendering speed had no significant effect on the breaking force values of the samples [19]. In calender bonding, the bonding pressure appears to have little or no effect on fabric performance beyond a certain minimum. Pressure also constrains the mobility of the fibres in the bond spot [18].

Longsheng et al. developed a composite nonwoven fabric from carbon fibres and polypropylene/polyethylene (PP/PE) sheath/core bicomponent fibres using a two-step wet papermaking/thermal bonding process. This composite nonwoven fabric, due to its mechanical robustness, compact structure and remarkable electrical properties, can be used as an electrode for energy storage devices [20]. Dedov and Nazarov studied mechanical properties of needle punched nonwoven fabrics produced from polyester and bicomponent fibres [21]. Kim et al. developed a nonwoven fabric from polyethylene terephthalate (PET) hollow fibres and two types of bicomponent fibres using carding, needle punching and thermal bonding processes for the replacement of polyurethane foams in car interiors [22]. Suvari, investigated acoustical behaviour of spunbonded nonwovens produced from bicomponent islands-in-the-sea filaments consisting of nylon 6 and polyethylene used as islands and the sea polymers respectively. The filaments were fibrillated by hydro entangling process. Results have shown multi-layer nonwoven with 108 islands were better acoustic absorbers than that of nonwoven with 1, 7, 19, 37 islands [23]. Fages et al. developed flax nonwoven fabric with different content polyvinyl alcohol and bicomponent polyamide6/co-polyamide (PA6/coPA) in 10-30wt.% ranges using wet-laid and thermal bonding technology for sound absorbers and thermal insulation applications [24]. Zhang et al. developed spunbonded nonwoven fabric from 70% PET and 30% PA6 bicomponent hollow segmented pie filaments using bicomponent spunbond technology for filtration applications. The hollow segmented pie bicomponent fibres were splitted to microfibers and bonded mechanically by high-pressure water-jets [25]. Doh et al. manufactured composite carboxymethyl cellulose (CMC) nonwoven fabric composed of CMC and PE/PP bicomponent fibres by using 85/15% v/v of ethanol/water solution as a dispersion medium by wet-laid nonwoven process as wound dressing materials for medical applications [26].

In this study, tensile properties of the needle punched and thermally bonded nonwoven fabrics produced from staple PET polyester fibres and sheath/core (50/50) low melting staple polyester binder fibres used at specific blending ratios such as 5%, 10%, 20%, 30%, 40% and 50% by using the carding, needle punching and pressing machines were studied. In this regard, the effect of sheath/core low melting staple polyester binder fibre ratio on tenacity of the mechanically needle punched and thermally bonded nonwoven fabric by pressing was investigated.

2. EXPERIMENTAL STUDY

2.1. Material and Method

In this study, 6 denier 55 mm semi dull DACRON® polyester staple fibres at a crimp frequency 3.8crimp/cm with white colour supplied from SASA Turkey were used as carrier fibre. TiO_2 about 0.30% was used for giving whiteness and brightness to the polyester fibre. 4 denier 51mm sheath/core low melting staple polyester binder fibres with an average staple length of 51-52 mm, with fineness average 4.58 denier and with black colour supplied from Toray Company were used as binder fibre. These fibres are mainly used in the production of needle punched fabric and acquisition distribution layer/fabric (ADL). Table 1 and Table 2 present major properties of used Dacron® polyester staple fibre and sheath/core low melting staple polyester binder fibre (Figure 1).

Table1-Characteristics of Staple Dacron® Polyester Fibre

Fibre Fineness (denier)	6
Fibre Fineness (dtex)	6.7
Fibre Staple Length (mm)	55
Breaking Tenacity (g/den)	4.3
Breaking Tenacity (cN/tex)	38
Breaking Elongation (%)	50
Number of Crimp (crimp per cm)	3.8
Diameter (µm)	25-26

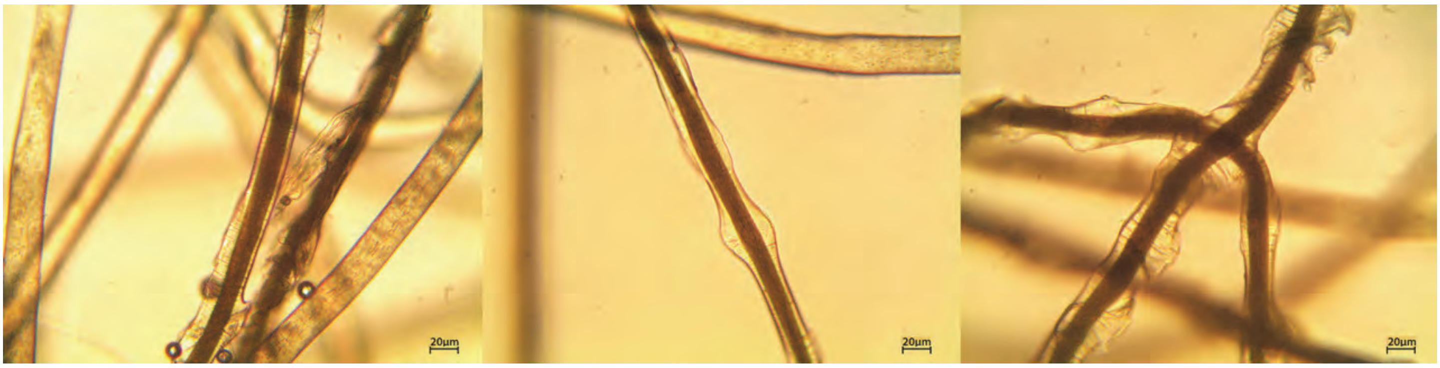

Figure 1. Sheath/Core Low Melting Staple Polyester Binder Fibre

Table2-Characteristics of Sheath/Core Low Melting Staple Polyester Binder Fibre

Fibre Fineness (denier)	4.58
Fibre Staple Length (mm)	51-52
Breaking Tenacity (g/den)	3.61
Elongation (%)	44.2
Sheath/Core Ratio	50/50
Diameter (µm)	24-26
Number of Crimp (number per inch)	8-9

Typical cross-section of sheath/core low melting staple polyester binder fibre was shown in Figure2. Low melting staple polyester binder fibre was of sheath/core (50/50) type with a round cross section; core of conventional polyester and a sheath of co-polyester with a melting point of 110°C.

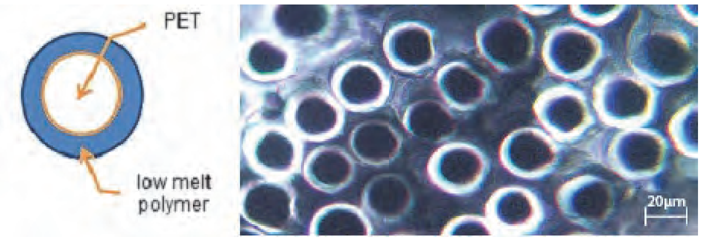

Figure2-Cross Section of Sheath-Core (50/50) Low Melting Staple PET Polyester Binder Fibre

2.2. Production Method

In the experimental study, 337A Mesdan laboratory type sample carding machine was used for making webs as you can see in figure 3. The machine has average 4 kg per hour production capacity and 10-15 meters per minute web delivery speed. Motor working revolution of the carding machine is 1400 rpm. Working feeding width and web width of the carding machine is 430 mm and 480 mm, respectively. The major parts of the equipment are a wide conveyor, a pair of feed rollers, three pairs of workers and strippers, main carding cylinder, doffing roller, fancy roller and clearer together with a web collecting drum. Oscillating doffing comb transfers the web onto a revolving drum to enable the fibre to build up to the required thickness.

Firstly, staple polyester fibres and low melting staple polyester binder fibres were weighted according to blending ratio. These fibres were blended by hand before carding machine and then fed into the carding machine. These fibre mixtures were run through the carding machine two times, first time for opening the fibres and second time for blending. Webs were produced at the end of the laboratory scale carding machine. The webs were wound on rotating drum. After web forming, bonding of fibres was carried out in the needle punching machine.

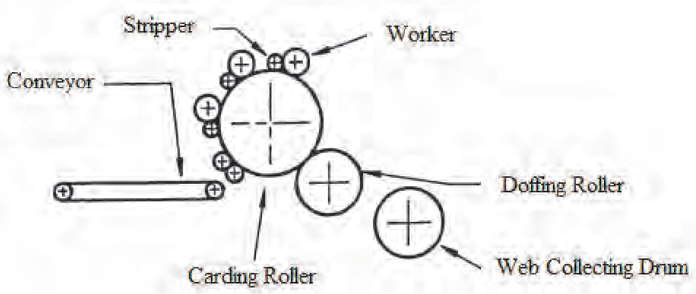

Figure3-Major Parts of the Mesdan 337A Carding Machine

Table3-Working Parameters of Laboratory Type Carding Machine

	Diameter (mm)	Production speed (m/min)
Carding roller	430	342,4
Doffing roller	330	7,74
Workers	115	3,98
Strippers	60	115,5
Web delivery speed	-	15

Bonding of the webs was carried out at needle punching machines by using barbed felting needles. Carded batts were needled at a needle punching process consisting of pre-needling (Figure 4), down-stroke needle punching and up-stroke needle punching machines (Figure 5). Production was done at industrial type needle punching machines with 15x18x40x3.5/3.0 R222 G3067 Groz-Beckert type needles instead of laboratory type needle punching machine. 72.3punch needling density per cm^2 and 14mm needle penetration depth at pre-needling machine was applied to webs. Pre-needled nonwoven fabrics were bonded in the down-stroke and up-stroke needle punching machines at 122.3punch/cm^2 and 122.8punch/cm^2 needling density and 6.5mm and 6.0mm needle penetration depth respectively. In pre-needling machine, thickness of the webs was reduced and the webs were stabilized. Fibre batt compression is particularly important in pre-needling operation. Fibre blends in the pre-needled nonwoven fabrics were greatly entangled and interlocked at down-stroke and up stroke needle punching machines. Major needle punching machine parameters were listed in Table 4.

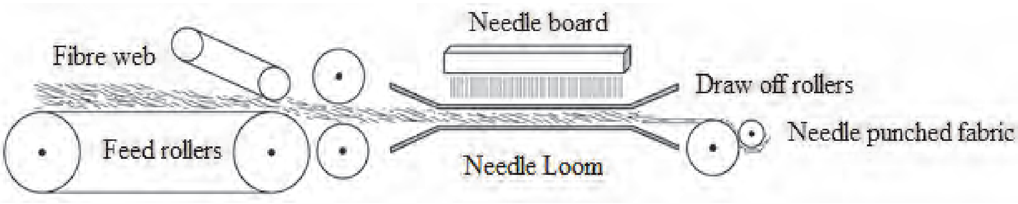

Figure 4. Schematic of the Pre-Needling Machine [27]

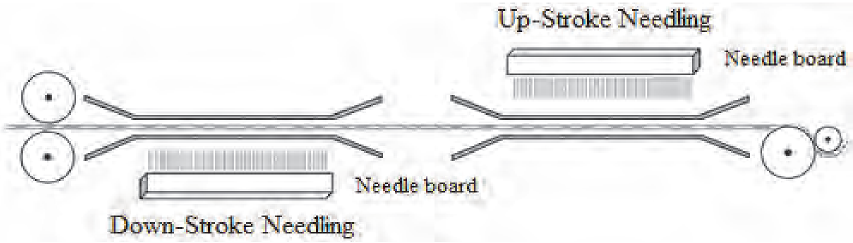

Figure 5. Needle Punching Machines with Down-Stroke and Up-Stroke [27]

Table4-Needle Punching Parameters

Needling Parameters	Pre-Needling Machine	Down-Stroke Needle Punching Machine	Up-Stroke Needle Punching Machine
Stroke Frequency (stroke/min)	558	919	950
Punch density (punch/cm^2)	72.3	122.3	122.8
Needle Penetration Depth (mm)	14	6.5	6.0

Needle punched nonwoven fabrics were thermal bonded by pressing at Hürsan Pres machine for melting of low melting fibre. Heat-pressing parameters were set to 140°C for 120 second under average 98bar pressure. Fabrics can be seen in Figure 6.

2.3. Testing Methods

Fabric area density (g/m^2), thickness (mm), tenacity (cN/tex) and elongation (%) at break properties of the mechanically needle punched and thermally bonded nonwoven fabrics were tested according to ISO and ASTM standards.

2.3.1. Thickness Test

Thickness of textile fabrics is determined as the distance between the upper and the lower surfaces of the material, measured under a specified pressure. Thickness of needle punched and thermally bonded nonwoven fabrics was measured using R&B Cloth Thickness Tester produced from James H.Heal&Co.Ltd Halifax England in accordance with TS EN ISO 9073-2 standard. Thickness values of needle punched and thermally bonded nonwoven fabric was measured at a pressure of 1g per cm^2 and 5g per cm^2 pressure respectively and measured values were averaged. Average of thickness of five samples cut from each nonwoven fabric was calculated [28, 29].

2.3.2. Tensile Strength Test

Tensile strength test of needle punched and thermally bonded nonwoven fabrics was carried out using Instron 4411 tensile testing machine as specified in ASTM D5035-06 Standard Test Method for Breaking Force and Elongation of Textile Fabrics according to strip method. Tensile strength and elongation at break values were obtained. Nonwoven fabric tenacity was determined according to equation 1. Tensile strength of nonwovens is usually expressed in term of tenacity (cN/tex) [32]. Five samples were taken both machine direction (MD) and cross direction (CD). The samples used in the tensile tests were cut as rectangular strips of 50mmx175mm dimensions. Test length was adjusted to 75 mm. Test speed was 300 mm per minute. A mean of five test results has been calculated in both machine direction (MD) and cross direction (CD). Needle punched and thermally bonded nonwoven fabric samples were conditioned at 65%±2°% relative humidity and temperature of 20±2°C prior to each test at physical testing laboratory of Marmara University Technology Faculty Textile Engineering Department.

Nonwoven fabric density (g/cm^3) was calculated; dividing fabric area density (g/m^2) by fabric thickness (mm). [30, 31]

$$\text{Fabric tenacity (cN/tex)} = \frac{\text{breaking strength (cN)}}{\text{fabric test width (mm) x fabric area density } (g/m^2)} \quad (1)$$

$$\text{nonwoven fabric density } (g/cm^3) = \frac{\text{fabric area density } (g/m^2)}{\text{fabric thickness (mm) x 1000}} \quad (2)$$

3. RESULTS

Table 5 presents fabric area density, thickness and nonwoven fabric density of needle punched and thermally bonded nonwoven fabrics. As the sheath/core low melting polyester binder fibres were mostly used between 5% and %50 ranges in nonwoven industry, the ratio of binder fibre was limited to %50. It was clearly seen that thickness of needle punched and thermally bonded nonwoven fabrics decreased with increase of sheath/core low melting staple polyester binder fibre ratio. It was observed that as the sheath/core low melting polyester binder fibre ratio increased, the nonwoven fabric density increased too.

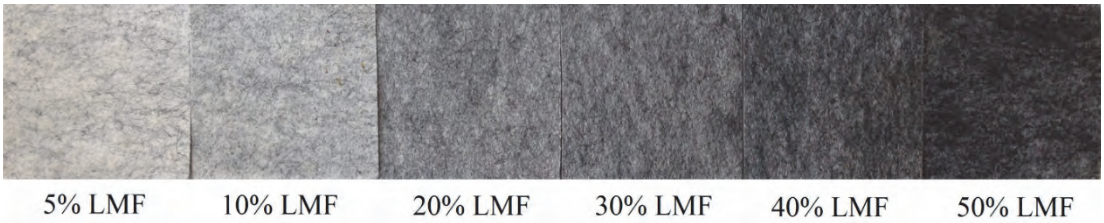

Figure 6. Needle Punched, Thermally Bonded Nonwoven Fabrics with Sheath/Core Low Melting Polyester Staple Binder Fibre (LMF)

Table5-Main Properties of Needle Punched and Thermally Bonded Nonwoven Fabrics

Nonwoven Fabrics Compositions	**Fabric Area Density (g/m^2)**	**Thickness (mm)**	**Nonwoven Fabric Density (g/cm^3)**
%5 Sheath/Core Low Melting Fibre %95 Staple Pes Fibre	363*, (12.14)**	0.79*, (0.09)**	0.459
%10 Sheath/Core Low Melting Fibre %90 Staple Pes Fibre	407*, (19.86)**	0.76*, (0.08)**	0.536
%20 Sheath/Core Low Melting Fibre %80 Staple Pes Fibre	398*, (8.96)**	0.69*, (0.07)**	0.577
%30 Sheath/Core Low Melting Fibre %70 Staple Pes Fibre	460*, (19.92)**	0.67*, (0.07)**	0.687
%40 Sheath/Core Low Melting Fibre %60 Staple Pes Fibre	388*, (15.42)**	0.52*, (0.06)**	0.746
%50 Sheath/Core Low Melting Fibre %50 Staple Pes Fibre	379*, (16.25)**	0.49*, (0.04)**	0.773

*Average Value, **Standard Deviation

As indicated in Table 5, it was proved that as sheath/core low melting polyester binder fibre ratio increased from 5% to 50%, thickness values of needle punched and thermally bonded nonwoven fabrics nonlinearly decreased from 0.79 mm to 0.49 mm. The highest thickness at about 0.79 mm was seen at needle punched and thermally bonded nonwoven fabric with 5% low melting polyester fibre ratio. In contrast, the lowest thickness at about 0.49 mm was found at needle punched and thermally bonded nonwoven fabric with 50% polyester binder fibre ratio. Otherwise, it was seen that as the low melting polyester binder fibre ratio increased from 5% to 50%, nonwoven fabric density increased from 0.459 g/cm^3 to 0.773g/cm^3.

Fabric tenacity and elongationat break properties of needle punched and thermally bonded nonwoven fabrics were given both machine direction and cross direction. Table 6 shows fabric area density, fabric tenacity and elongation at break values of the produced needle punched and thermally bonded nonwoven fabrics at machine direction.

Low melting fibres and bicomponent fibres are used instead of chemical agents to increase tensile strength and stiffness of nonwoven fabrics. It was proved that sheath/core low melting polyester fibre ratio used as binder fibre has a crucial impact on fabric tenacity of the needle punched and thermally bonded nonwoven fabric.

Fabric tenacity was calculated; dividing breaking strength (cN) by fabric test width (mm) multiplied with fabric area density (g/m^2). Table 6 indicates that fabric tenacityof needle punched and thermally bonded nonwoven fabrics was in the range of 2.997 cN/tex to 5.221 cN/tex, and elongation at break of needle punched and thermally bonded nonwoven fabrics was in the range of 87.60% to 30.78% in machine direction.

Table 7 indicates fabric area density, fabric tenacity and elongation at break of the produced needle punched and thermally bonded nonwoven fabrics at cross direction.

Table6- Test results of needle punched and thermally bonded nonwoven fabrics in machine direction (MD)

Nonwoven Fabrics Compositions	Fabric Area Density (g/m^2)	Fabric Tenacity (cN/tex)	Elongation at Break (%)
%5 Sheath/Core Low Melting Fibre %95 Staple Pes fibre	365*, (6.56)**	2.997*, (0.20)**	87.60*, (5.52)**
%10 Sheath/Core Low Melting Fibre %90 Staple Pes	397*, (7.46)**	3.078*, (0.30)**	74.99*, (3.39)**
%20 Sheath/Core Low Melting Fibre %80 Staple Pes	394*, (5.96)**	3.162*, (0.19)**	40.55*, (12.13)**
%30 Sheath/Core Low Melting Fibre %70 Staple Pes	466*, (18.39)**	3.824*, (0.49)**	25.18*, (1.79)**
%40 Sheath/Core Low Melting Fibre %60 Staple Pes	378*, (9.23)**	4.873*, (0.43)**	24.55*, (2.84)**
%50 Sheath/Core Low Melting Fibre %50 Staple Pes	393*, (17,48)**	5.221*, (0.56)**	30.78*, (3.14)**

*Average Value, **Standard Deviation

Table7- Test results of needle punched and thermally bonded nonwoven fabrics in cross direction (CD)

Nonwoven Fabrics Compositions	Fabric Area Density (g/m^2)	Fabric Tenacity (cN/tex)	Elongation at Break (%)
%5 Sheath/Core Low Melting Fibre %95 Staple Pes fibre	360*, (9.67)**	0,855*, (0.08)**	162*, (14.48)**
%10 Sheath/Core Low Melting Fibre %90 Staple Pes	416*, (19.86)**	0,889*, (0.11)**	137*, (27.16)**
%20 Sheath/Core Low Melting Fibre %80 Staple Pes	402*, (10.51)**	1,184*, (0.23)**	4,86*, (0.71)**
%30 Sheath/Core Low Melting Fibre %70 Staple Pes	453*, (22.82)**	1,903*, (0.44)**	8,72*, (1.28)**
%40 Sheath/Core Low Melting Fibre %60 Staple Pes	397*, (17.58)**	2,247*, (0.51)**	13,43*, (1.37)**
%50 Sheath/Core Low Melting Fibre %50 Staple Pes	365*, (5.75)**	2,575*, (0.40)**	18,32*, (0.38)**

Table 7 shows that fabric tenacity of needle punched and thermally bonded nonwoven fabrics was in the range of 0.855 cN/tex to 2.575 cN/tex and elongation at breakof needle punched and thermally bonded nonwoven fabrics was in the range of 162% to 18.32% for cross direction. These results indicate that fabric tenacity of needle punched and thermally bonded nonwoven fabrics was improved with increase of sheath/core low melting polyester binder fibres at cross direction. It is remarkable that as 30% and higher polyester binder fibre ratios were used, fabric tenacity of the needle punched and thermally bonded nonwoven fabrics at cross direction seriously increased.

As shown in figure 7, fabric tenacity values of needle punched and thermally bonded nonwoven fabrics increased with increase of sheath/core low melting polyester binder fibre ratio both machine direction and cross direction.

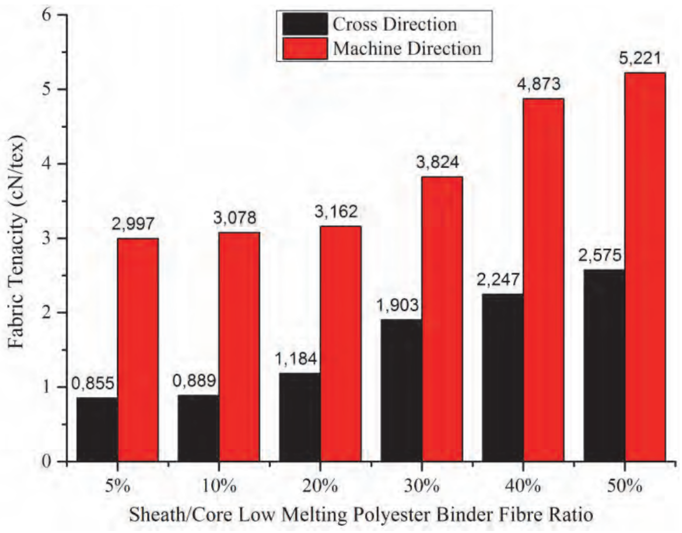

Figure 7. Fabric tenacity results of the needle punched and thermally bonded nonwoven fabrics

The effect of sheath/core low melting polyester binder fibre ratio on fabric tenacity of needle punched and thermally bonded nonwoven fabrics was shown in Figure 7. It was observed that fabric tenacity at machine direction was higher than cross direction at all fabrics. There are significant differences between measured fabric tenacity of needle punched and thermally bonded nonwoven fabrics at machine and cross direction. It was seen that as the sheath/core low melting polyester binder fibre ratio increased, the fabric tenacity differences between machine and cross direction decreased.

The results indicated that nonwoven fabric tenacity increased with increase of sheath/core low melting polyester binder fibre ratio. This can be explained by the fact that the polyester binder fibres have high bonding force. It was found that as the sheath/core low melting polyester fibre ratio increased from 5% to 50%, fabric tenacity values of needle punched and thermally bonded nonwoven fabrics for machine and cross direction increased about 75% and 200% respectively. The fabric tenacity values of needle punched and thermally bonded nonwoven fabrics with 5%, 10% and 20% sheath/core low melting polyester fibre ratio are similar to each other. But, it is remarkable that as the content of sheath/core low melting polyester binder fibre was 30% and higher, the fabric tenacity of needle punched and thermally bonded nonwoven fabrics dramatically increased both machine and cross direction.

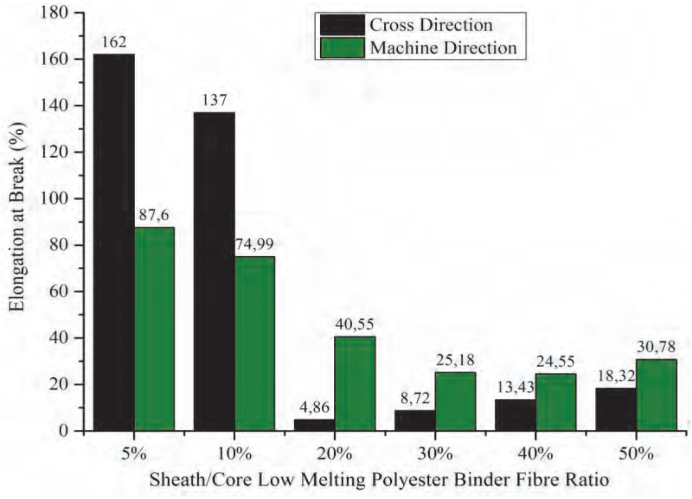

Figure 8. Elongation at break values of needle punched and thermally bonded nonwoven fabrics

The effect of sheath/core low melting polyester binder fibre ratio on elongation at break of needle punched and thermally bonded nonwoven fabrics was shown in Figure 8. It was noted that the nonwoven fabrics with 5% and 10% sheath/core low melting polyester binder fibre had higher elongation at break than that of needle punched and thermally bonded nonwoven fabrics with 20%, 30%, 40% and 50% polyester binder fibre ratio in both machine and cross direction.

It was seen that the elongation at break values of needle punched and thermally bonded nonwoven fabrics decreased with increase of polyester binder fibre ratio in the range of 5% to 40% in the machine direction. It was observed that as the low melting polyester binder fibre ratio was 50%, elongation at break of nonwoven fabric started to increase in machine direction. This rise can be attributed to an increase in the number of crossover points between low melting polyester binder fibres.

In cross direction, it was seen that as the polyester binder fibre ratio was 20%, the needle punched and thermal bonded nonwoven fabric exhibited a sharp decrease at elongation at break. Elongation at break values of needle punched and thermally bonded nonwoven fabrics started to increase with increase of polyester binder fibre ratio in the range of 20% to 50% in the cross direction. This rise can be attributed to an increase in the number of crossover points between low melting polyester binder fibres [6].

The correlation between sheath/core low melting polyester binder fibre ratio and fabric tenacity of needle punched and thermally bonded nonwoven fabrics was shown in Figure 9 and Figure 10. A strong positive linear correlations with R^2=0.92 and R^2=0.97 were recognised in machine and cross direction respectively. R^2=1 indicates a very great interrelationship between these factors. As a result of this, it was understood that there was a strong positive correlation between sheath/core low melting polyester binder fibre ratio and fabric tenacity. This can be attributed to melting of low melting fibre, bonding to each other and other polyester base fibres. It was seen that correlation in the cross direction was stronger than that of machine direction.

The correlation between sheath/core low melting polyester binder fibre ratio and elongation at break of needle punched and thermally bonded nonwoven fabrics was shown in Figure 11 and Figure 12. A weak downhill negative correlations with R^2=0.74 and R^2=0.61 were recognised in machine and cross direction. It was understood that as R^2=1 indicates a very great interrelationship between these factors, there was not distinct correlation between elongation at break and sheath/core low melting polyester binder fibre ratio especially in cross direction. It was seen that correlation in the machine direction was stronger than that of cross direction.

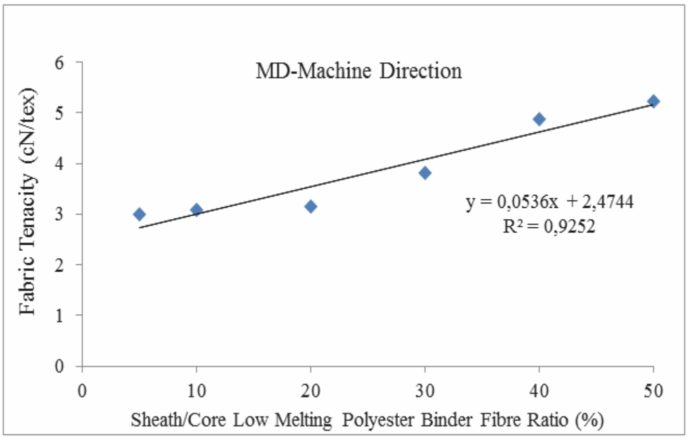

Figure 9. Correlation between sheath/core low melting polyester binder fibre ratio and fabric tenacity of nonwoven fabric in machine direction

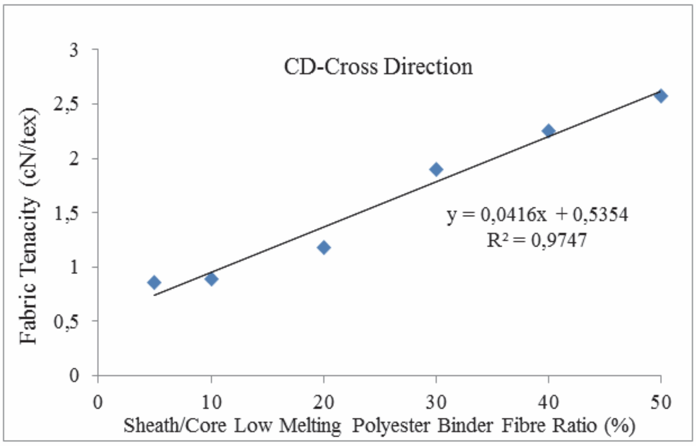

Figure 10. Correlation between sheath/core low melting polyester binder fibre ratio and fabric tenacity of nonwoven fabric in cross direction

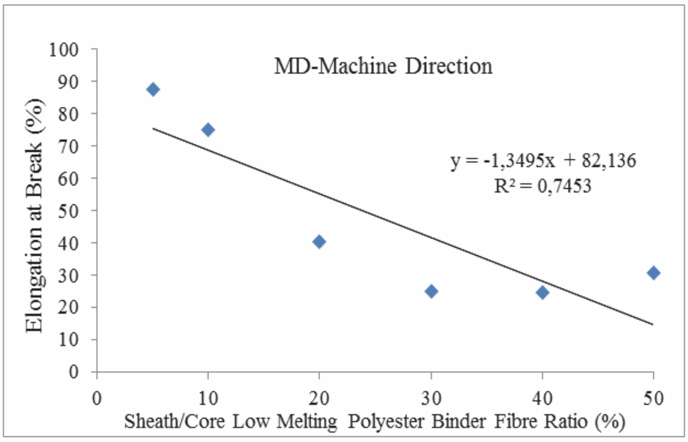

Figure 11. Correlation between sheath/core low melting polyester binder fibre ratio and elongation at break of nonwoven fabric in machine direction

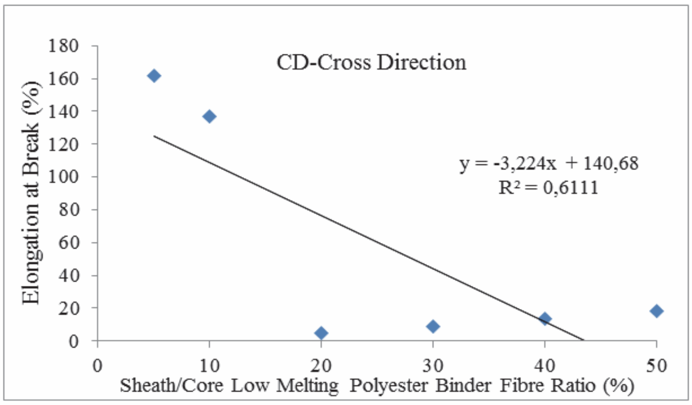

Figure 12. Correlation between sheath/core low melting polyester binder fibre ratio and elongation at break of nonwoven fabric in cross direction

4. CONCLUSION

In this study, tenacity properties of the needle punched and thermally bonded nonwoven fabrics produced from staple polyester carrier fibre and sheath/core low melting staple polyester binder fibres by using carding, needle punching and pressing machine were investigated. The main goal of study was to determine the effect of sheath/core low melting polyester binder fibre ratio on fabric tenacity properties of needle punched and thermally bonded nonwoven fabrics.

The sheath/core low melting staple polyester binder fibres were blended with staple polyester carrier fibres at 5%, 10%, 20%, 30%, 40% and 50% ratios. The nonwoven fabric production was carried out at carding, needle punching and pressing machines.

Sheath/core low melting polyester binder fibre ratio was the only one variable which influences tenacity properties of needle punched and thermally bonded nonwoven fabrics.

The experimental results showed that the fabric tenacity of needle punched and thermally bonded nonwoven fabrics values in the machine and cross direction increased with the increase of sheath/core low melting polyester binder fibre ratio. It was seen that as the content of sheath/core low melting polyester binder fibre in nonwoven fabric was 30% and higher, tenacity properties of needle punched and thermally bonded nonwoven fabrics significantly increased in machine and cross direction.

Thickness of nonwoven fabrics considerably decreased with increase of sheath/core low melting staple polyester binder fibre ratio. It was found that elongation at break values decreased considerably with increase of sheath/core low melting staple polyester binder fibre ratio. It was remarkable that as the sheath/core low melting polyester binder fibre ratio was 50%, elongation at break started to increase in machine direction. In addition to that, it was seen that as the content of polyester binder fibre ratio was 30% and higher, elongation at break values of needle punched and thermally bonded nonwoven fabrics started to increase in the cross direction. This rise can be attributed to an increase in the number of crossover points between low melting polyester binder fibres.

The experimental study and findings revealed that there was a high linear positive correlation between nonwoven fabric tenacity and sheath/core low melting polyester binder fibre ratio used at production of the needle punched and thermally bonded nonwoven fabrics.

It is expected that the usage of low melting or bicomponent binder fibre will increase instead of chemical binder in the future.

ACKNOWLEDGEMENT

The author would like to thank Hassan Group and Hassan Textile Company for the technical support.

REFERENCES

1. Özen, M.S.; Sancak, E.: (2016) “Investigation of Tensile Properties of Nonwoven Fabrics Produced from Recycled Staple Polyester and Sheath/core Low Melting Staple Polyester Fibres by Using Carding, Needle Punching, Calendaring and Pressing Machines”, International Nonwoven Technical Textiles Technology Magazine, September&October, Number56, pp.42-55.
2. http://www.toray.com/news/fiber
3. Dasdemir, M.; Maze, B.; Anantharamaiah, N.; Pourdeyhimi, B.: (2012) “Influence of Polymer Type, Composition, and Interface on the Structural and Mechanical Properties of Sheath/core Type Bicomponent Nonwoven Fibers”, Journal of Material Science, (2012), 45, pp.5955-5969.
4. Turbak, A.F.: “Nonwovens: Theory, Process, Performance, and Testing, Chatper2: Nonwoven Terminology WlliamE.Houfek”, Tappi Press, (1993), pp. 11, 167.
5. Akalın, M.; Özen, M.S.: “Tülbent Esaslı Dokunmamış Kumaşlar”, (Nonwoven Fabrics)”, NesilMatbaacılık, Istanbul (2010)
6. Kellie, G.: (2016), “Advances in Technical Nonwovens”, Woodhead Publishing, Number:181, UK.
7. Russell, S.J.: (2007) “Handbook of Nonwovens”, Woodhead Publishing in Textiles, CRC Press.
8. Horrocks, A.R.; Anand, S.C.: (2000), “Handbook of Technical Textiles”, CRC Press, Boca Raton, USA.
9. Berlin, A.A.; Joswik, R.; Vatin, N.I.: (2016) “Engineering Textiles-Research Methodologies, Concepts, and Modern Applications”, AAP Apple Academic Press, Canada, pp.14.
10. Nawab, Y.: (2016), Textile Engineering, Walter de Gruyter GmbH, Germany.
11. Maity, S.; Singha, K.: “Structure-Property Relationship of Needle-Punched Nonwoven Fabric”, Frontiers in Science, Vol.2 (6), (2012), pp.226-234
12. Midha, V.K.; Mukhopadyay, A.: “Bulk and Physical Properties of Needle-Punched Nonwoven Fabrics”, Indian Journal of Fibre&Textile Research, Vol.30, (2005), pp.218-229.
13. Saghafi, R.; Zarrebini, M.; Moezzi, M.: “Mechanical Properties of Needle-Punched Fabrics in Relation to Fiber Orientation”, Journal of Textiles and Polymers, Vol.5, No:1, (2017-Jan), pp.48.
14. Kang, T.J.; Jung, K.H.; Park, J.K.; Youn, J.R.: “Effect of Punching Density on the Mechanical and Thermal Properties of Needle-Punched Nonwoven Carbon/Phenolic Composites”, Polymers& Polymer Composites, Vol.10, No.7, (2002), pp.521-530.

15. Anandjiwala, R.D.; &Boguslavsky, L.: “Development of Needle-Punched Nonwoven Fabrics from Flax Fibers for Air Filtration Applications”, Textile Research Journal, (2008), Vol.78, pp.614-624.

16. Ventura, H.; Ardanuy, M.; Capdevila, X.; Cano&Jose, F.; Tornero, A.: “Effects of Needling Parameters on Some Structural and Physico-Mechanical Properties of Needle-Punched Nonwovens”, The Journal of The Textile Institute, Vol.105, No.10, pp.1065-1075.

17. Desai, A.N.; Balasubramanian, N.: “Critical Factors Affecting the Properties of Thermal-Bonded Nonwovens with Special Reference to Cellulosic Fibres”, Indian Journal of Fibre&Textile Research, Vol.19, September, (1994), pp.209-215.

18. Michielsen, S.; Pourdeyhimi, B.; Desai, P.: “Review of Thermally Point-Bonded Nonwovens: Materials, Processes, and Properties, Journal of Applied Polymer Science, Vol.99, Issue:5, (2006), pp.2489-2496.

19. Bahari, N.; Hasani, H.; Zarrebini, M.; Hassanzadeh, S.: “Investigating the Effects of Material and Process Variables on the Mechanical Properties of Low-Density Thermally Bonded Nonwovens Produced from Estabragh (milkweed) Natural Fibers”, Journal of Industrial Textiles, Vol.46, Issue:3, (2016), pp.719-736.

20. Lu, L.; Xing, D.; Xie, Y.: (2016) “Electrical Conductivity Investigation of a Nonwoven Fabric Composed of Carbon Fibers and Polypropylene/Polyethylene Sheath/core Bicomponent Fibers”, Materials&Design, Vol.112, pp.383-391

21. Dedov, A.; Nazarov, V.G.: (2015) “Processed Nonwoven Needle Punched Materials with Increased Strength”, Fibre Chemistry Vol.47, Issue2, pp.121-125

22. Kim, K-Y.; Doh, S.J.; Im, J.N.: (2013) “Effects of Binder Fibers and Bonding Processes on PET Hollow Fiber Nonwoveens for Automotive Cushion Materials”, Fibers and Polymers, Vol.14, Issue4, pp.639-646.

23. Suvari, F.; Ulcay, Y.; Maze, B.: (2013) “Acoustical Abrorptive Properties of Spunbonded Nonwovens Made from Islands-in-the-Sea Bicomponent Filaments”, Journal of the Textile Institute, Vol.104, Issue4, pp.438-445

24. Fages, E.; Cano, M.A.; Girones, S.: (2013) “The Use of Wet-Laid Techniques to Obtain Flax Nonwovens with Different Thermoplastic Binding Fibers for Technical Insulation Applications”, Textile Research Journal, Vol.83, Issue4, pp.426-437.

25. Zhang, H.; Qian, X.; Zhen, Q.: (2015) “Research on Structure Characteristics and Filtration Performances of PET-PA6 Hollow Segmented-Pie Bicomponent Spunbond Nonwovens Fibrillated by Hydro Entangle Method”, Journal of Industrial Textiles, Vol.45, Issue1, pp.48-65

26. Doh, S.J.; Lee, J.Y.; Lim, D.Y.: (2013) “Manufacturing and Analyses of Wet-Laid Nonwoven Consisting of Carboxymethyl Cellulose Fibers”, Fibers and Polymers, Vol.14, Issue12, pp.2176-2184.

27. Gordon, S.; Hsieh, Y-L.: (2007) “Cotton: Science and Technology”, Woodhead Publishing Limited, Cambridge, England, pp508.

28. Federova, N.: (2006) “Investigation of the Utility of Islands-in-the-Sea BicomponentFiber Technology in the Spunbond Process”, PHd Thesis, North Caroline State University, pp.79.

29. Demirci, E.: “Mechanical Behaviour of Thermally Bonded Bicomponent Fibre Nonwovens: Experimental Analysis and Numerical Modelling”, Loughborough University, (2011), pp.37.

30. Midha, V.; Mukhopadyay, A.: “Bulk and Physical Properties of Needle-Punched Nonwoven Fabrics”, Indian Journal of Fibre&Textile Research, Vol.30, June **(2005)**, pp.219

31. Ghali, L.; Halimi, M.T.; Hassen, M.B.; Sakli, F.: “Effect of Blending Ratio of Fibers on the Properties of Nonwoven Fabrics Based on Alfa Fibers”, Advances in Materials Physics and Chemistry, (2014), 4, pp.116-125.

32. Tracton, A.A.: “Coatings Materials and Surface Coatings”, CRC Press, (2007), pp.68-9