Analysis of Ultrasonic Seam Tensile Properties of Thermal Bonded Nonwoven Fabrics

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ABSTRACT

Ultrasonic seam strength and elongation at break properties of thermal bonded nonwoven fabrics are discussed in this study; and the effects of fiber type, fabric area density, and roller type on ultrasonic tensile properties of nonwoven fabrics are reported. Polypropylene (PP), Polyester (PES), and Polyamide – Polyester (70% PA - 30%PES) blend of thermal bonded nonwoven fabrics were used, and the seam strength and elongation at break were measured and the obtained data were evaluated. At the end of the experimental studies, the data from the ultrasonic tensile properties of thermal bonded nonwoven fabrics which were made of different fibers and same production method were evaluated in order to determine the tensile properties which lead to the best result. The experimental results show that the PP thermal bonded nonwoven fabric tended to provide the best seam strength and elongation at break values.

INTRODUCTION

The enormous development in nonwoven technology has provided nonwoven fabrics that are more often used in daily life. It is common to see filters, personal care, and automotive products on supermarket shelves, and new products appear on a daily basis [1].

Nonwovens are made by assembling staple fibers or infinitely continuous filaments fibers on top of each other and bonding them together via a mechanical, thermal, or chemical process. The majority of air filters, wipes, insulations, barrier fabrics, surgical masks, cosmetic/hygiene products, and diapers are made of such nonwoven materials. Nonwovens can be dense and strong, as in woven fabrics, or porous and compressible, as in foams.

Manufacturing nonwovens typically consist of three major steps; fiber spinning, formation of fiber web (fiber assembly), and fiber bonding [2].

Three major bonding types can be employed: chemical bonding, thermal bonding, and mechanical bonding. The developments of the past few years have shown that the share of thermally bonded webs has grown constantly [3].

The basic idea for thermal bonding was first introduced by Reed in 1942. Initial products used rayon as the carrier fiber and plasticized cellulose acetate (PCA) or vinyl chloride (PVC) as the binder fiber. Since then, there have been different developments in this field [4, 5].

Thermal bonding is now the most popular method of bonding used in nonwovens. The viability of the thermal bonding process is rooted in the price advantage obtained by lower energy costs. The development of new raw materials, better web formation technologies, and higher production speeds have made thermal bonding a viable process for the manufacture of both durable and disposable nonwovens [5, 6].

The main advantages of thermal bonding are low raw material and energy costs, product versatility, better product quality characteristics, high production rate, and low space requirement. It is an environmentally clean technology, as no chemicals are used. There is no weight loss after washing and no water pollution, as in chemical bonding. The products have a soft feel and are absorbent and permeable. Insulation products and composites can also be made. It is ideal for making waddings and paddings used in winter clothing [5-7].

Several types of thermal bonding methods are used, namely area-bonding, point-bonding, air oven bonding, ultrasonic bonding, hot calendar bonding, and radiant bonding. Point bonding is the most widely used thermal bonding method [6].

Hot calendar bonding makes fabric stiffer, thinner, and stronger; whereas hot air bonding results in loftier, thicker and lower strength products [8].

Thermal calendar bonding is one of the most economical and widely used techniques in nonwoven manufacturing [9]. In this process, a pre-consolidated web is passed through the nip of two rolls pressed against each other at a desired pre-set pressure and heated internally to a desired temperature [10].

A number of studies related to thermal bonded nonwovens have been conducted. The studies made by Bhat and others report morphology and structure properties of thermal bonding of films, fibers, and nonwovens [6, 9, 11-18] Structures, mechanical properties and tensile strength behaviors, and compression theories of thermal bonded nonwovens were examined by Rawal and others in their studies [19-23].

Single-use nonwovens have been very important for the medical field for over 40 years. Usage began with facemasks and expanded to sterilization wrap, specialty drapes, gowns, galoshes, bones, surgical caps and masks. These medical nonwovens are invaluable in products as drape sheets, surgical gowns, adult pads and underpads of nonwoven structures. Nonwovens are easily processable textile surfaces in apparel industry for specific end uses and it provides great convenience in storage and identification, equipment, labor and inventory [24, 25].

Also nonwovens provide relatively inexpensive, lightweight and effective protection [26].

Nonwoven fabrics are textile structure whose importance is increasing day by day. From the perspective of clothing, using nonwoven fabric for especially disposable clothing is of great importance especially in terms of cost. However, conventional stitch types create mechanical damage on nonwoven fabrics and hampers mobility. Therefore, the use of ultrasonic stitch is inevitable for sewing of nonwoven fabrics.

Studies of ultrasonic energy have aroused the interest of researchers and implementers in textile applications in recent years. Although ultrasonic energy is used in textile industry widely [27-40], the applications are very limited in apparel industry. The main reason of that is ultrasonic sewing is not used widely in apparel industry for assembling of woven and knitted fabrics because of the fact that ultrasonic seam tensile properties are not desirable for woven and knitted fabrics [41].

Nonwoven fabrics, used in surgical gown, single-use products, medical and hygienic products, hold an important place in medical purposes. Ultrasonic sewing is even more preferred than other conventional sewing types in the production of nonwoven based products. The main reason for this is that the structure of nonwoven fabrics is more suitable for ultrasonic sewing.

Ultrasonic sewing is the best way to assemble nonwoven fabrics for single use products such as facemasks, gloves, surgical gowns etc. Therefore effect of production methods of nonwoven fabrics on the properties of ultrasonic sewing such as seam strength and elongation at break should be investigated.

Using of ultrasonic energy as sewing process in readymade garment production is also improving. Sewing process can be defined as assembling of cut fabrics by using proper machines to obtain a cloth [42]. Conventional sewing process is performed by discontinuous assembly and perforated stitch. For the continuous assembly and without perforated stitch, other sewing methods should be used. Ultrasonic, laser and heat assembly methods are performed by melting and cooling of the joined thermoplastic surface [43]. Ultrasonic sewing is an effective method to assembly the thermoplastic materials in industry. Ultrasonic sewing finds application in automotive industry, medical and hygienic products, sports, work and protective wears, covering and packaging, underwear, filter and technical textiles [44]. Ultrasonic assembly technology uses high frequency vibration to join two or more thermoplastic materials. No needle and yarn are required for the ultrasonic sewing. Assembly process is performed by the melting and bonding of the material [41, 45].

The first main fiber and fabric assembly application of this technology was performed in 1970s. Invention of Branson ultrasonic sewing machine was revolutionary in 1970s for the sewing of the fabrics without needle and yarn. Kuttruff investigated the mechanism of the ultrasonic welding in 1991. A similar research was repeated by Abramov in 1994. Material properties and material content of the ultrasonic sewing applications and ultrasonic sewing mechanism were investigated by Kuttruff in 1994. Finally, factors which effect the ultrasonic welding strength and placement of the optic fibers into the fabrics by using ultrasonic welding were investigated by Shi and Little in 2000 [43].

Also, sewing processes of the nonwoven and woven fabrics by using ultrasonic sewing method were studied in recent years. Boz and Erdogan compared the ultrasonic sewing and double pressure sewing of the woven and nonwoven fabrics [44]. In another study it was reported that better bonding was achieved by using polypropylene-polypropylene and polyester-polyester fabrics [43]. Kayar et al. investigated the effect of the fiber type on the tensile properties of the ultrasonic sewing. In this study woven fabric was used [42]. Mistik et al. compared the tensile properties of the ultrasonic, lock and chain sewing methods. In their study woven fabric was used and the result of their study shows that ultrasonic seam tensile properties were lower than the other lock and chain sewing methods [41].

When we look at the studies related to ultrasonic sewing in apparel, it can be said that there is not sufficient work on assembling of nonwoven fabrics with ultrasonic sewing and there is no study about ultrasonic sewing of thermal bonded nonwoven fabrics.

The aim of this study was, to investigate ultrasonic seam tensile properties on thermal bonded nonwoven fabrics. In this context, investigating the effect of fiber type, fabric area density, and roller type on the ultrasonic seamstrength and elongation properties of thermal bonded nonwoven fabrics is intended to provide an insight to researchers about this issue.

EXPERIMENTAL

Materials

In the experimental process, three types of nonwoven fabrics (PES – PA/PES – PP) at four different fabric area densities were used. Three different fibers were used in producing the thermal bonded nonwoven fabrics, the fibers were provided from Telasis Co., Istanbul. The properties of these fibers are shown in *Table I*.

Four different weight thermal bonded nonwoven fabrics of 100% PP, 100% PES and 70% PA – 30% PES were produced at the Telasis Co. using a carding machine at 20, 25, 35 and 50 g/m^2 and the fibers shown in *Table I*. The fiber webs were bonded thermally by using a thermal calendar bonding machine at Telasis Co., Istanbul.

TABLE I. Properties of fibers.

Fibers	Density (g/cm^3)	Length (mm)	Elongation at Break (%)	Tenacity (cN/tex)	Fiber Crimp (cm)	Shrinkage (%)	Finish on Fiber (%)	Softening Point (ºC)	Melting Point (ºC)
Polyester (PES) 1.7 dtex	1.41	40	35	39.6	4	5 (196ºC - 30 min)	14,5	80-110	250-360
Polyamide (PA) 1.7 dtex	1.14	40	82	49	6.5	1.7 (Hot air)	24	90-95	250-265
Polypropylene (PP) 2.2 dtex	0.90	40	160	19	14	<3 (120ºC - 10 min)	35	140-150	160-175

As seen in *Table I:*

- PP fiber has the lowest fiber density and tenacity value in comparison with other fibers.
- The fiber lengths of the used nonwoven fabrics are same.
- Elongation at break value of the PP fiber is slightly higher than other fibers. The reason of that PP filament is MOY (Middle Oriented Yarn) and has more crimps than other fibers. Crimp is a term used to describe the waviness of a fiber [46, 47]. Crimp in a fiber is desirable because it makes easy to process the fiber into a variety of forms such as a spun yarn [48]. Crimp is measured by either the number of crimps or waves per unit length [46]. Gong and others, in their study, indicated that crimp effected the mechanical properties of nonwoven fabrics. In their study, this effect was clarified by mentioning that crimp had roles which enabled fibers to bond more and it decreased distribution of fabric more size [49]. In another study conducted by Scharcanski and others, it was concluded that as crimp was increased isotropic structures tend to present smaller mean voids, higher mean number of fibers per zone and higher total number of bond per fiber than anisotropic structures [50].
- PA fiber has the highest tenacity value.
- PES fiber has the highest shrinkage value.
- Shrinkage is reduction in length and or width of a textile material as a result of treatments during processing or use [51]. As a fiber is produced, a complex organization of polymer molecules takes place that involves developing both orientation and crystallinity in the fiber. This organization results in molecular stress in the fiber. If either thermal or chemical energy is supplied to the fiber, the polymer molecules may become sufficiently mobile to relieve the stress by dis-orientation and recrystallization, this process occurs on a molecular level and is manifest on the macro level by fiber shrinkage [52].
- Highest content of the antistatic substance was applied to PP fiber (35%). Because moisture absorption properties of the PP fiber are lower than other fibers.

  Finish on fiber values, define the quantity of the antistatic substances on the fiber, and describes the antistatic substance as kg per 100 kg of fiber. Finishing processing, physical or chemical, that is applied to a textile material that improves the appearance, handle or performance [51]. Finish for staple fibers is quite important as static charges and improper cohesiveness can lead to problems in fiber processing such as roller lapping. The spin finishes for staple fibers generally consist of tow cohesion sarcosides, antistatic agents like $POCl_3$-based esters, a large amount of water, and ethoxylates of different fatty acids [47].

TABLE II. Production parameters of thermal bonded nonwoven fabrics.

Fabrics	**Calendar Temperature (^{0}C)**	**Calendar Speed**	**Pressure**
Polyester (PES)	230 ^{0}C	18 – 25 g / m^2 = 110 m / min. 30 – 50 g / m^2 = 80 m / min.	60 N / mm
Polyamide - Polyester (PA-PES) (70% - 30%)	200 ^{0}C	18 – 25 g / m^2 = 90 m / min. 30 – 50 g / m^2 = 70 m / min.	60 N / mm
Polypropylene (PP)	145 ^{0}C	18 – 25 g / m^2 = 200 m / min. 30 – 50 g / m^2 = 140 m / min.	80 N / mm

Production parameters of thermal bonded nonwoven fabrics produced are given in *Table II*.

The properties of the fabrics obtained from these fibers are shown in *Table III*. Test results given below for the thermal bonded nonwoven fabrics are based on Machine Direction (MD) using an Instron 4411 and TS EN ISO 13934-1. Each test was repeated 10 times [53].

TABLE III. The Properties of Thermal Bonded Nonwoven Fabrics.

Fabric Type	**Raw Materials**	**Production Method**	**Fabric Area Density (g/m²)**	**Tensile Strength (N)**	**Tensile Strength (% CV)**	**Elongation at Break (%)**	**Elongation at Break (% CV)**
Thermal Bonded	Polyester (PES) Staple Fibers	Carding And Thermal Bonding	20	16.97	4.71	12.03	6.78
			25	20.01	6.41	11.58	7.74
			35	27.95	4.54	11.65	6.31
			50	45.01	6.12	09.43	6.66
Thermal Bonded	Polyamide - Polyester (PA-PES) (70%- 30%) Staple Fibers	Carding And Thermal Bonding	20	5.98	5.12	17.70	5.88
			25	8.04	4.87	17.01	7.75
			35	10.00	5.78	13.87	6.34
			50	15.98	6.22	12.48	6.29
Thermal Bonded	Polypropylene (PP) Staple Fibers	Carding And Thermal Bonding	20	32.95	5.41	40.30	6.75
			25	40.01	6.78	44.58	7.11
			35	67.96	5.11	58.23	5.82
			50	94.93	5.65	62.51	6.94

Tensile strength of all fabrics increased with increasing area density of the fabric as shown in *Table III*. PP fabric had the highest tensile strength result while PP fibre had the lowest tenacity. This is due to low density of the fiber as a result of more fibers in a fabric structure. Low tensile strength of PA/PES blends is due to low tensile strength and fiber entanglement rate of PA.

According to the *Table III*, the rates of elongation at break properties of PES and PES / PA decreased with increasing weight of the fabric, PP fabric, on the contrary, increased. The reason is that PP fiber has low density, so fiber content of the PP nonwoven fabric in unit area is higher than other nonwoven fabrics. As a result the elongation of the PP nonwoven fabric is increased with the increasing of the fibers per unit area and fabric surface density. Also PP fiber is more appropriate for the thermal bonding process than other fibers.

Ultrasonic Sewing Process

Thermal bonded nonwoven fabrics were sewn by using a Sonimak Ultrasonic Sewing machine model of EGR-015 (*Figure 1*). Mechanical vibration of the machine at the contacted surface was 25-30 microns. Machine vibration was 20.000 times (20kHz) per second. Pressure of the roller was 2.2 kg/cm^2. Speed of the machine was 2 m/min (May reach to 35-40m/min).

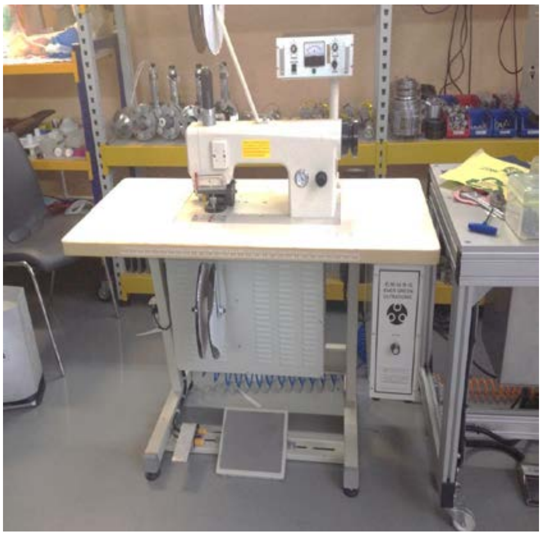

FIGURE 1. EGR – 015 Sonimak ultrasonic sewing machine.

The Ultrasonic sewing process was performed by using 2 and 4 row rollers (*Figure 2*).

FIGURE 2. Rollers.

Sewing surface area occupied by the 2 row roller used was measured as 0.257 cm^2 / cm^2; and by the 4 row roller used was 0.578 cm^2 / cm^2 (*Figure 3* and *4*).

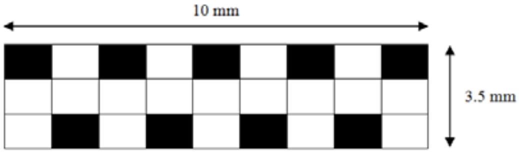

FIGURE 3. Sewing surface area for 2 rows roller.

When *Figure 3* carried out sewing, the area was calculated as 0.35 cm^2 for 1 cm length. There were 27 points in that area, so 77.14 points were placed in 1 cm^2 and 25.7% of these points formed the sewing connection surface.

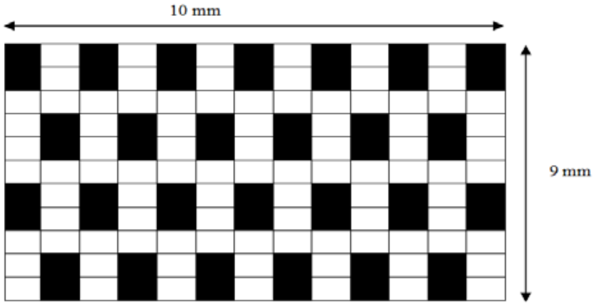

FIGURE 4. Sewing surface area for 4 rows roller.

When *Figure 4* carried out sewing, the area was calculated as 0.9 cm^2 for 1 cm length. There were 143 points in that area, so 158.9 points were placed in 1 cm^2 and 57.8% of these points formed the sewing connection surface.

When two rollers were compared as connection points in unit length, the number of the connection points of the roller 4 and the roller 2 were 26 points/cm and 9 points/cm, respectively.

Ultrasonic sewing machine was adjusted to 20 kHz frequency for the ultrasonic sewing process.

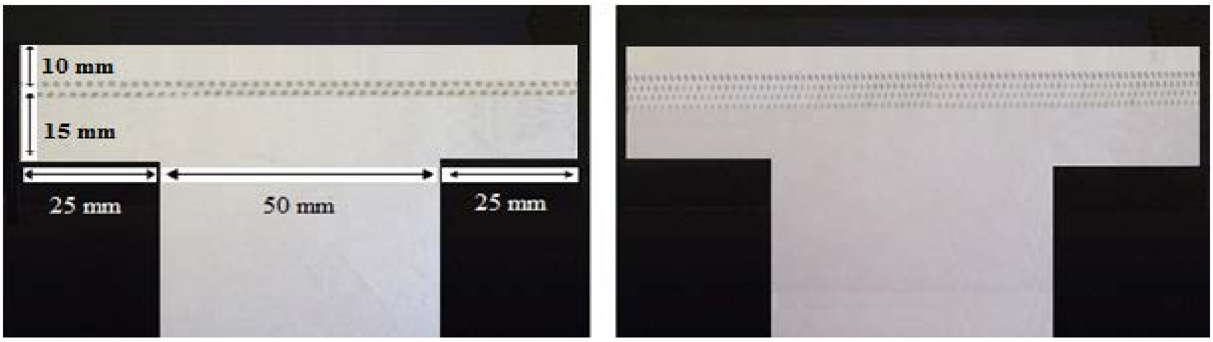

FIGURE 5. Photos of the sewn by 2 and 4 rows of roller nonwoven fabrics before seam strength test.

Seam Strength Test

Seam strength tests were performed according to the strip method, TSE 1619-1 EN ISO 13935-1 standard [54]. Fabrics were cut to 350x100mm, and then plied and stitched from 1 cm of the fabric edge. After the sewing process, fabrics were cut to 25 mm as shown in *Figure 5* before seam strength testing. Seam strength tests were performed by using an Instron 4411 testing instrument. Speed of the instrument was set to 100mm/min. 10 samples were tested for each roller and arithmetic averages of the test results were presented.

RESULTS AND DISCUSSION

Morphology of the Ultrasonic Seam

Ultrasonic seaming is a technique by which textile surfaces consisting of thermoplastic fibers are bonded by heat which occurs as a result of pressure and vibration [45]. With reference to the definition given above, it can be deduced that an ultrasonic stitch takes place when fibers which were initially unbound in nonwoven fabrics *(Figure 6),* bonded to one another by fusing in the stitch area by means of heat pressure and rapid cooling *(Figure 7).* After bonding the nonwoven surface thickness in the stitch area became thinner. Besides, there was an achromatic view upon pressure and fusion of fibers and ultrasonic the stitch area was glossier and harder than the fabric *(Figure 8).*

FIGURE 6. Microscopic image of the nonwoven fabric (x40).

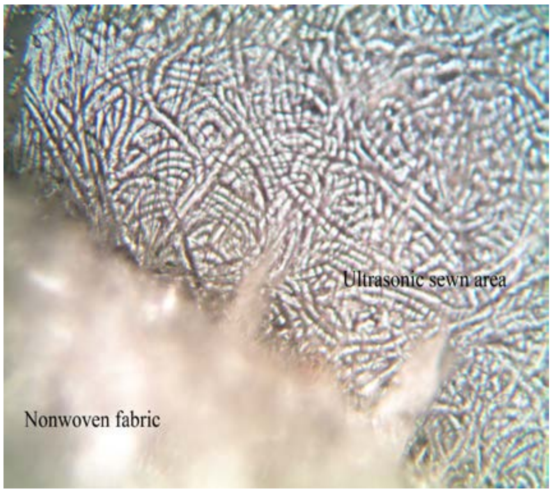

FIGURE 7. Microscopic images of ultrasonic seam area of the sewn nonwoven fabrics (x100).

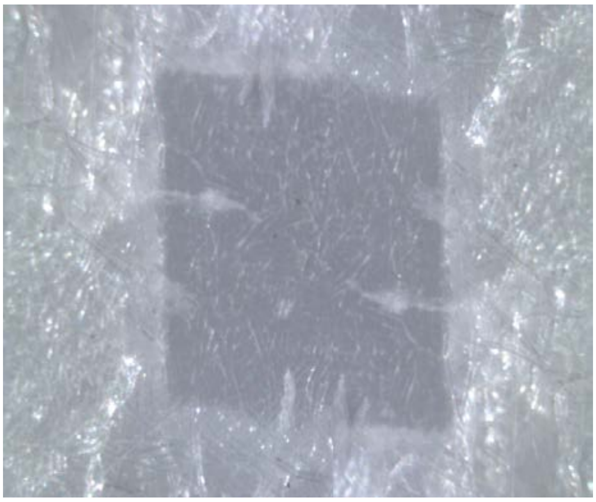

FIGURE 8. Microscopic images of the sewn nonwoven fabrics (x50).

As can be seen in *Figure 7*, the voids between fibers disappeared (*Figure 6*) as a result of the fibers in the stitch area bonding one another.

When the results of tensile strength test were analyzed, it was concluded that ultrasonic seam area has more tensile strength affected by the test in anyway. Failure mode came about in the corner of the stitch area where a pulling force was applied. When the results of failure mode of sewn nonwoven fabrics in tensile strength tests were examined, it was concluded that the failure mode for three fabrics are brittle. When the tensile strength test was made to examine the nonwoven fabrics, it was seen that the failure mode of these nonwoven fabrics was brittle before the ultrasonic stitch was applied. After tensile strength testing was conducted on the ultrasonic stitch area of these fabrics, the failure mode became brittle again as was expected *(Figure 9)*.

FIGURE 9. Microscopic images of the sewn nonwoven fabric after seam tensile test (x64).

As seen from *Figure 9*, the ultrasonic seam area fractured from the edge of the molten area. This shows that the ultrasonic sewing method is an effective method to bind the thermoplastic fibers.

Seam Tensile Strength Test

Seam strength and elongation at break values of the sewn nonwoven fabrics are given below.

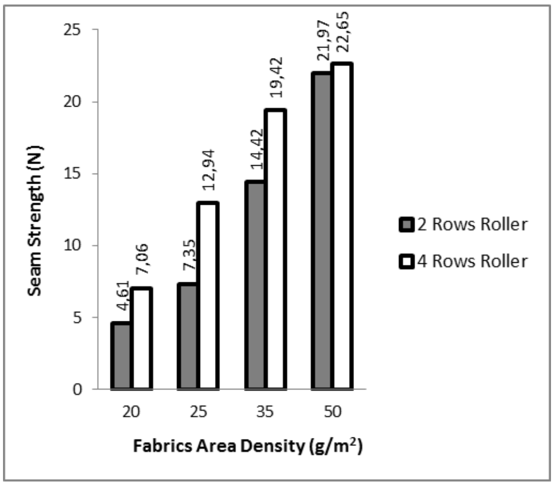

FIGURE 10. Ultrasonic seam strength values of PES fabric.

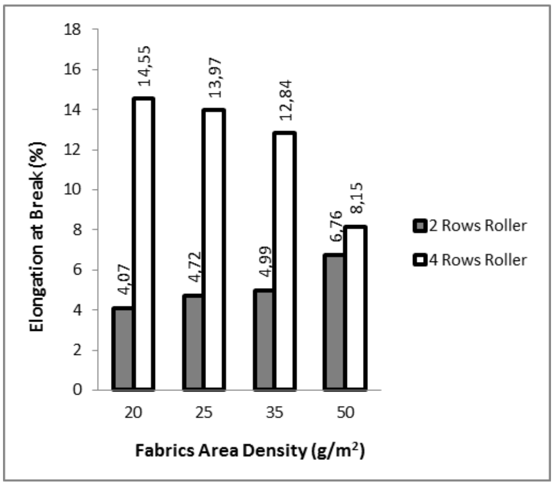

FIGURE 11. Elongation at break values of PES fabric.

Figure 10 shows the increase in seam strength as the fabric area density increased for both 2 and 4 row rollers.

For Polyester nonwoven fabrics sewn with 2 row rollers, as the area density increased, the elongation at break increased, while sewing with 4 row rollers, the elongation at break values decreased with increasing fabric area density.

The reason of the decrease of the elongation at break values of the sewn fabrics by using 4 row rollers was due to the high number of the connection points per unit length.

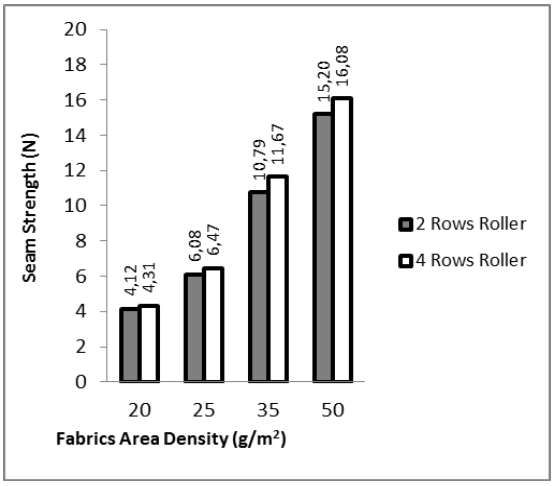

FIGURE 12. Ultrasonic seam strength values of PA - PES fabric

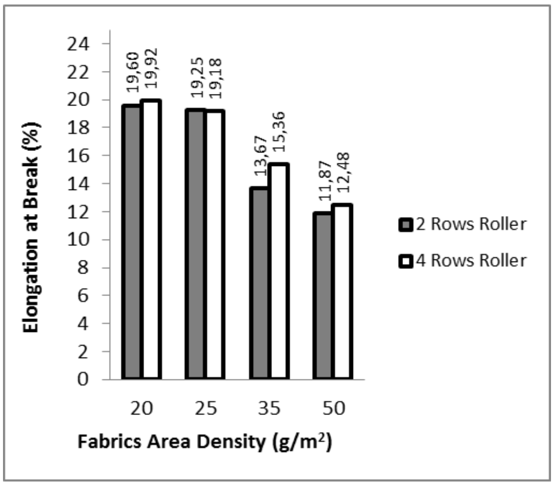

FIGURE 13. Elongation at break values of PA - PES fabric.

According to the *Figure 12*, it was observed that seam strength values increased with the increase of the area density of fabric after the sewing in both 2 row rollers and 4 row rollers for PA-PES blend of nonwoven fabric.

According to the *Figure 13*, as a result of sewing with 2 row and 4 row rollers, the values of elongation decreased by increasing weight density of the fabric for PA - PES blend nonwoven fabric.

Again, the above measurement results show that when tensile strength of 100% PES fabric is compared to the ultrasonic seam tensile strength of PES and PA-PES blend of nonwoven fabrics, the values were higher, therefore it was seen that the PA fiber blend reduced the strength of ultrasonic sewing. In the light of this information the strength of ultrasonic sewing in nonwoven fabrics produced from PA fiber decreased.

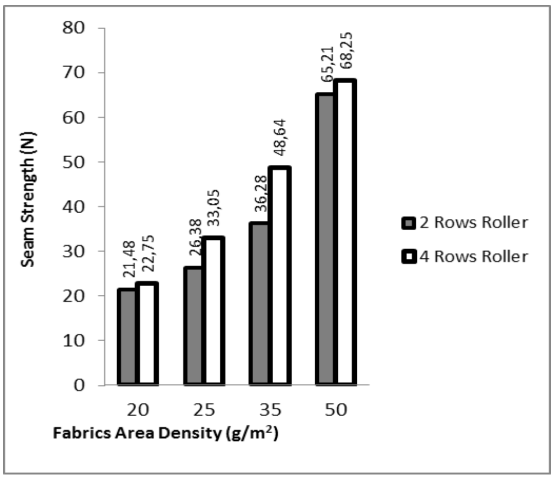

FIGURE 14. Ultrasonic seam strength values of PP fabric.

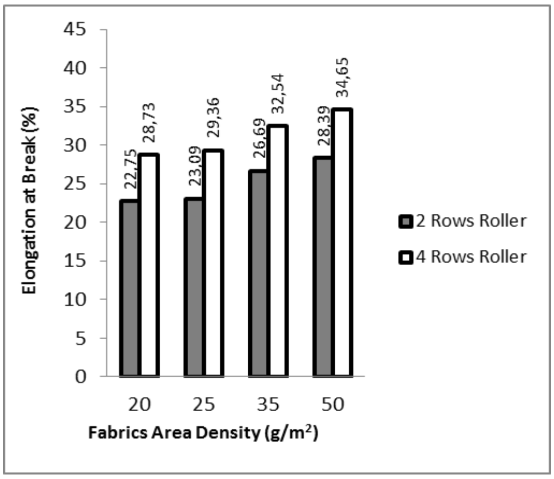

FIGURE 15. Elongation at break values of PP fabric.

According to the *Figure 14*, for PP nonwoven fabric after sewing with both 2 row rollers and 4 row rollers it was seen that seam strength values increased with increasing fabric area density.

According to the *Figure 15*, for PP nonwoven fabric as a result of sewing with 2 row rollers and 4 row rollers, it was observed that the values of elongation increased with the increase of fabric area density.

Thermal bonded PP fabrics were better than the PA and PES fabrics due to its low melting point. At the conditions studied, seam tensile strength of the PP fabrics was higher than the other fabrics because PP melted more easily at our process settings. Also PP fabrics had higher elongation at break values than the PES and the PA/PES fabrics due to its good thermal bonding properties.

When the tensile strength of fabrics used in the study is compared with seam tensile strength, it can be seen that seam tensile strength of fabrics PES, PA/PES and PP is lower than fabric tensile strength.

The arithmetic average of the rates of decline for fabrics each fabric area density were calculated as 58.92% for 2 row rollers, 43.47% for 4 row rollers in PES fabric, 13.15% for 2 row rollers, 7.53% for 4 row rollers in PA /PES blend fabric, 36.7% for 2 row rollers, 26.22% for 4 row rollers in PP fabric.

From the data above the maximum decrease in seam tensile strength occurred in PES fabric.

Also, it was seen that the decrease in seam tensile strength for each of the three fabrics is lower with 4 row roller sewing than with 2 row roller sewing. It can be said that this result is the reason for the higher seam tensile strength in sewing with 4 row roller sewing than with 2 row roller sewing.

CONCLUSION

This study investigated the effects of ultrasonic seams on thermal bonded nonwoven fabrics. The effects of fiber type, fabric area density, and ultrasonic seam bonding surface on ultrasonic seam strength and elongation at break properties were also investigated.

The results obtained within the scope of the research can be summarized as follows;

1. Ultrasonic seam tensile strength increased in a way parallel to the increase in fabric area density in all fabrics used in the study.
2. It was observed that the rollers used are effective in ultrasonic seam tensile strength, in parallel with the increase in the sewn surface.
3. At the conditions studied, PP fabric has the highest seam tensile strength, and it can be said that PP fabric is more advantageous in terms of tensile strength in the light of these results.
4. The high ratio of the PA affected the ultrasonic seam strength negatively.
5. The Ultrasonic sewing method is an effective method to assembling the nonwoven fabrics.

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