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The Effect of Fiber Orientation and Fiber Blend Ratio on the Permeability Properties of the Nonwoven Fabrics

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ABSTRACT

In this study, the effects of fiber laying direction (parallel or cross) which is also mentioned as fiber orientation, and fiber blend ratio on the permeability properties of nonwoven fabrics produced with viscose/polyester blends were investigated. For this purpose, nonwoven fabrics made of 50% viscose/50% polyester, 40% viscose/60% polyester, and 30% viscose/70% polyester were produced with card line, and to get the final fabric, these webs were overlaid prior to hydroentaglement bonding in parallel or cross directions. Then, air permeability properties, water vapor permeability, and capillary absorption properties were measured to determine the effect of fiber orientation and fiber blend ratio on the comfort related properties of the fabrics. It was found that the fiber blend ratios affected the comfort related properties of the nonwoven fabrics such as air and water vapor permeability and capillary absorption properties. In general, as the percentage of viscose fiber in the fabric decreased and the PES fiber ratio therefore increased, a decrease in the comfort properties of the fabrics was observed. Furthermore, the fiber orientation in the fabrics also played an important role in the comfort related properties. Since the fibers in the fabric structure were parallel to the machine direction in parallel laying, air permeability, capillary absorption (wicking), and water vapor permeability results of these parallel laid fabrics were higher compared to the cross-laid nonwoven fabrics in which the fibers were randomly placed.

1. Introduction

The first patented nonwoven production started with August Belford in 1854 by bonding the short fibers of the card noil with starch. Even if the history of nonwovens went long way back than 1854, there was no significant increase in the production at an industrial scale until the 1960s. After the 1960s within a decade, the nonwoven industry has grown commercially in America, and this was followed by West Europe, Japan, and Asian countries [1].

In today's world, the production and consumption of nonwovens have enormously increased due to the COVID pandemic. While the consumption of nonwoven products was 40000 tons in 1970 in Europe, the world consumed 2,3 million tons of nonwoven in the 2000s [1]. In 2019, the production of nonwovens only in European countries was 2,8 million tons [2]. The production of nonwovens in Greater Europe grew by 7.2% in 2020 to reach 3,075,615 tons with a total estimated turnover of €9,555 million [3]. The reason for the high production and increased use of nonwoven products is the pandemic. Nonwovens can be used in every field, especially in hygiene (28.7%), wipes for personal care (12.3%), construction (9.8%), automotive (6.2%), civil engineering (5.4%), filtration (3.6%), food & beverage (3.3%) [2]. This is because nonwoven products can be produced with different techniques and technologies which make them have versatile properties. Basically, nonwoven production is composed of two stages: web formation and web bonding. These stages include several possibilities of techniques that result in nonwovens having different properties.

Isotropy is very important in nonwoven products such as filters which means similar fiber orientation in different directions. Fiber orientation is a key parameter affecting the geometrical, hydraulic, and mechanical properties of nonwoven materials [4]. It is especially important for filter products since mechanical properties not only in the machine direction and cross direction, but in every possible direction, are supposed to be measured [5]. Unfortunately, fiber orientation during web formation in card machines is mainly along the machine direction. This causes anisotropy of the material, especially in mechanical properties such as stress-strain properties. This anisotropic property of the material can be decreased with several condensers and randomized cylinders in the carding line in addition to cross-lappers following carding machines. The fiber orientation in the web does not only affect the mechanical properties of the nonwovens. Besides, it also influences the sizes and structures of the pores on the web which changes the permeability and liquid transfer properties.

Many studies were done mainly in the field of needle-punched nonwovens. In a literature review of bulk and physical properties of needle-punched nonwoven fabrics, it was stated that higher strength results were obtained in the machine direction than the cross-direction of the parallel-laid needle-

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punched jute nonwoven fabrics [6]. Parallel-laid nonwoven fabrics have lower air permeability values compared to those of cross-laid nonwoven fabrics [6, 7]. In another study, different nonwoven fabrics were produced from reclaimed fibers by analytically changing the machine variables; and measurements of the air permeability, mechanical properties, pore size distribution, and filtration efficiency of the nonwoven fabrics were examined. The outcome of this study reflected an overall development in all filtration characteristics due to the calendaring operation [8]. Ray and Ghosh studied the fiber cross laying as well as fiber orientation angle in cross-laid needle-punched nonwoven fabric and its relationship with tensile properties of fabric. It was found that maximum tenacity was obtained in case of cross-direction (CD) and then the tenacity gradually reduces towards machine-direction (MD); and based on statistical analysis it was found that cross-laid needle-punched nonwoven fabrics possessed reasonable isotropy in respect of both fiber orientation and tenacity in all fabrics [9]. Ahmad and his colleagues studied the use of comber noil in the production of hydroentangled nonwovens at varying water jet pressures and conveyor speeds. The results showed that these variables can help to manufacture fibrous assemblies with engineered properties, according to required application area [10]. The effect of laying directions on the mechanical and comfort properties of nonwoven fabrics produced with 100% polyester, and polyester/viscose blended was investigated [11, 12]. It was found that increasing the parallel web ratio in the cross direction decreased the breaking strength values; on the contrary, increasing the parallel webs ratio in the machine direction increased the breaking strength values of the final product based on the fiber orientation

In this study, the effect of laying directions (parallel or cross) and the blend ratio on the permeability properties of nonwoven fabrics produced with viscose/polyester fibers was investigated. For this purpose, nonwoven fabrics made of viscose/polyester blends in different ratios were produced with card line and these webs were parallel-laid or cross-laid to obtain the final fabric. Then, air and water vapor permeability properties, and capillary absorption properties of the fabrics were measured to determine the effect of web-laying direction and the blend ratios of the produced fabrics on the permeability and the capillary absorption properties of these fabrics.

2. Materials and Methods

To examine the effect of fiber orientation and the fiber blend ratios on the permeability capillary absorption properties of the produced nonwoven fabrics, the same production line of carding machine + hydroentaglement bonding was used to reduce the variation between the fabric samples. Parallel and cross laid webs of 45 (g/m2) grams per square meter with three different blend ratios of viscose/polyester fibers were produced. The blend ratios were 50% viscose/50% polyester, 40% viscose/60% polyester, and 30% viscose/70% polyester. The specifications of the webs used in the study were given in Table 1.

The nonwoven fabrics produced in this study were produced in the parallel and cross production lines and the produced webs were bonded with hydroentanglement (water jet method). Production line consists of 6 different stages such as web formation, web-laying, web-bonding, drying, finishing, and packaging/packing.

All samples were conditioned under laboratory conditions (20ºC ± 2 and 65±2% relative humidity) for 24 hours. Air permeability tests were performed with ten repetitions according to TS 391 EN ISO 9237 (Determination of permeability of fabrics to air) standard. A 20 cm² test area was placed in the circular sample holder by applying sufficient stretching force on the test sample so that there were no

Table 1. Materials used in the study and their properties

Pattern	Web Laying Direction	Fiber type and ratio	Blend ratio (Fiber %, fineness(denier)-length (mm)	Weight (g/m²)
1. Plain	Parallel	50 % Viscose/50 % PES	%50 CV; 1.7-38 %30 PES; 1.7-38 %20 PES; 1,6-38	45
2. Plain	Cross	50 % Viscose/50 % PES	%50 CV; 1.5-38 %30 PES; 1.6-38 %20 PES; 1.7-38	45
3. Plain	Parallel	40 % Viscose/60 % PES	%40 CV; 1.5-38 %30 PES; 2.8-38 %30 PES; 1.7-38	45
4. Plain	Cross	40 % Viscose/60 % PES	%40 CV; 1.5-38 %40 PES; 2.8-38 %20 PES; 1.7-38	45
5. Plain	Parallel	30 % Viscose/70 % PES	%30 CV; 1.7-38 %30 PES; 2.8-38 %40 PES;1.7-38	45
6. Plain	Cross	30 % Viscose/70 % PES	%30 CV; 1.5-38 %20 PES; 2.8-38 %25 PES; 1.7-38 %25 PES; 1.7-51	45

CV:Viscose, PES:Polyester

wrinkles. After the air suction device was started, the air flow passing through the specific area of the test sample was gradually increased until a pressure difference of 200 Pa was reached between the two sides of the fabric and the amount of air passing through the fabric was recorded as l/m²/sec.

The water vapor permeability test of nonwoven fabrics was carried out by the Cup Method according to ASTM E 96-Water Vapor Transmission of Materials standard. In the method, the samples cut with a diameter of 10 cm were placed on a 9 cm diameter container containing distilled water and sealed with wax. By closing the perimeter of the containers, the escape of water vapor is also prevented. Three samples were taken from each fabric sample in parallel and cross-laid directions. The weights of the containers were weighed at 24-hour intervals under physical textile laboratory conditions for 3 days, and the slopes obtained from the weight loss-time graphs were determined for each sample. The water vapor transmission rates of the fabrics were found by dividing the calculated slope values by the surface areas of the containers used in the experiments.

The measurement of the capillary absorption rate of the fabrics (also called wicking or liquid transmission rate) was performed according to DIN 53924 standards. The fabric samples prepared by cutting 20 cm in length and 4 cm in width were attached to a plastic ruler with paper clips in a vertical position, a weight was attached from the bottom and dipped 1 cm from the lower end into the 1% K_2CrO_4 (Potassium Chromate) solution. After 60 seconds, the length of rise of the solution in the fabric is determined in mm. Two repeated measurements were done from each type of fabric.

All the results were analyzed with statistical methods and evaluated with graphics to express the effects of fiber orientation and blend ratios on the permeability and capillary absorption properties of the produced nonwoven fabrics.

3. Results and Discussion

In Fig.1 air permeability results and in Table 2 variance analysis of the produced fabrics are presented. It is obvious that the fiber orientation in the final nonwoven fabrics which were produced with parallel-laid or cross-laid process had a statistically significant effect on the air permeability properties of the fabrics. Air permeability of the parallel-laid nonwoven fabrics was higher compared to those of the equivalents which were cross-laid because the fiber orientation in parallel-laid fabrics showed a more uniform laying structure and regular placement compared to the fiber orientation in cross-laid fabrics. There was also an effect of blend ratio on the air permeability of the nonwoven fabrics. When the results were evaluated in detail, it was found that decreasing ratio of viscose fiber and therefore increasing ratio of polyester fiber in the blends of the nonwoven fabrics produced with both parallel and cross-laying caused a decrease in the air permeability results of the fabrics. However, this effect was not found to be statistically significant (Table 2).

Water vapor properties of the nonwoven fabrics are important in various fields especially in clothing comfort. Nowadays, for most of the linings or layers of a multi-layered clothing, nonwoven fabrics are used. Thus, it is important to determine the water vapor permeability of the nonwoven fabrics and the parameters that play a significant role. For this reason, results of water vapor permeability of the fabrics are presented in Fig. 2 and the variance analysis of the fabrics in Table 3. Both fiber orientation and blend ratio parameters had statistically significant effect on the results. First, if the fibers were laid in parallel in the webs, the water vapor permeability of the fabrics were higher than the fabrics in which the fibers were laid in cross direction. This result was also consistent with the one that was obtained in the air permeability results. The porosity in the fabrics in which fibers were laid parallelly was higher than the ones in the fabrics in which fibers were laid in cross direction. The second parameter affecting the water vapor permeability was the blend ratio, and regardless of fiber orientation, decreasing viscose fiber ratio and therefore cellulosic nature which makes them hydrophilic. This property made the fibers absorb more water vapor from the media and transfer it to the atmosphere. On the other hand, PES fibers are hydrophobic in their nature and increasing the PES ratio in the fabrics decreased the ability of water vapor permeability of the fabrics.

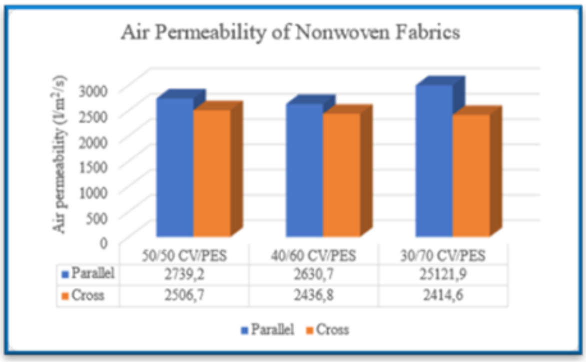

Fig. 1. Air permeability results of the nonwoven fabrics.

Table 2. Variance analysis of air permeability results of the nonwoven fabrics.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Fiber orientation (A)	474548,27	1	474548,27	22,26	**0,000**	4,02
Fiber blend ratio (B)	40989,43	2	20494,72	0,96	0,389	3,17
Interaction (AxB)	241094,23	2	120547,12	5,65	**0,006**	3,17
Error	1151402,00	54	21322,26			
Total	1908033,93	59				

Capillary absorption rate of the textiles is another important property which affects the clothing comfort. This property is also important in products such as medical textiles. In Fig.3 the capillary absorption results of the fabrics are presented both in machine and cross directions. The variance analysis of the results in both directions are presented in Table 4 and Table 5. When the variance analysis of capillary absorption results of the nonwoven fabrics in either direction was examined in detail, both parameters of fiber orientation and fiber blend ratio had a statistically significant effect ($p<0,05$). Fiber blend ratio had a higher effect compared to fiber orientation (Table 4 and 5). It is important to understand the mechanism of the liquid transmission of a fabric. When the first fiber in the fabric meets the water, fiber absorbs the water and when it is filled up with water, fiber starts to transmit the water to the next structure. Therefore, the fiber characteristics play significant role. The hydrophilic or hydrophobic fiber affects the capillary absorption. Natural fibers have irregularities in their structures because of their origins, and man-made fibers are regular due to the manufacturing processes; therefore, regular, or irregular fiber structures also influence the capillary absorption tendencies. A regular structure responds to water more quickly than an irregular structure. When the results were examined in detail, decreasing viscose fiber ratio, and increasing PES fiber ratio caused a decrease in the wicking results regardless of machine or cross direction due to the hydrophobic characteristic of PES fibers. In addition to fiber ratio, fiber orientation also influenced the capillary absorption results. Nonwoven fabrics produced with parallel fiber orientation had higher values of capillary absorption compared to the ones produced with cross fiber orientation. This is because of regular and irregular structures. Nonwoven fabrics with parallel fiber orientation had more regular structure compared to the ones with cross fiber orientation.

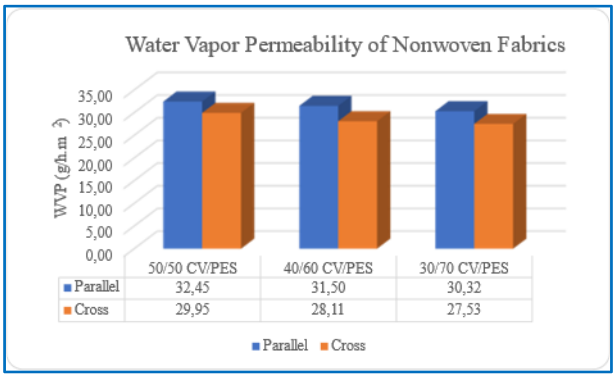

Fig. 2. Water vapor permeability (WVP) results of the nonwoven fabrics.

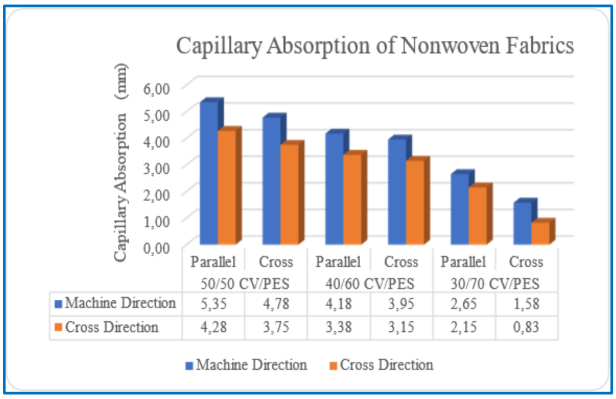

Fig. 3. Capillary absorption in mm of the nonwoven fabrics.

Table 3. Variance analysis of water vapor permeability results of the nonwoven fabrics.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Fiber orientation (A)	12,56	1	12,56	121,89	**0,01**	18,51
Fiber blend ratio (B)	5,26	2	2,63	25,55	**0,04**	19,00
Error	0,21	2	0,10			
Total	18,03	5				

Table 4. Variance analysis of wicking results of the nonwoven fabrics in MD direction

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Fiber orientation (A)	2,34	1	2,34	50,68	**0,00**	4,41
Fiber blend ratio (B)	36,01	2	18,01	389,33	**0,00**	3,55
Interaction (AxB)	0,73	2	0,37	7,89	**0,00**	3,55
Error	0,83	18	0,05			
Total	39,92	23				

Table 5. Variance analysis of wicking results of the nonwoven fabrics in CD direction.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Fiber orientation (A)	2,87	1	2,87	17,86	**0,00**	4,41
Fiber blend ratio (B)	26,90	2	13,45	83,71	**0,00**	3,55
Interaction (AxB)	1,29	2	0,65	4,02	**0,04**	3,55
Error	2,89	18	0,16			
Total	33,96	23				

4. Conclusion

Since nonwoven fabrics used in the study had the same weight per unit area and produced with the same pattern, the fiber blend ratios affected the comfort related properties of the fabrics such as air and water vapor permeability and capillary absorption properties. In general, as the percentage of viscose fiber in the fabric decreased and the PES fiber ratio increased, a decrease in the comfort properties of the fabrics was observed. Besides fiber ratio in the blend, the fiber orientation in the fabrics also played an important role in the comfort properties. The results of air permeability, capillary absorption and water vapor permeability were high for the fabrics produced with parallel laying since the fibers were placed parallel to the machine direction. Air permeability, capillary absorption and water vapor permeability of the fabrics produced with cross laying were lower than in parallel laying direction since the fibers were randomly placed in the cross-laid direction.

Declaration

Author Contribution: Conceive-P.G.Ü.; Design- P.G.Ü.; Supervision- P.G.Ü.; Experimental Performance, Data Collection and/or Processing- P.G.Ü.; Analysis and/or Interpretation- P.G.Ü.; Literature Review- P.G.Ü.; Writer-P.G.Ü.; Critical Reviews– P.G.Ü.

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