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An Investigation on Abrasion Resistance and Bending Rigidity of Recycled Nonwovens Including Blanket Trimmings

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ABSTRACT

In this study blanket trimmings and mechanically recycled fibers were blended and softly pre-needlepunched to be used as innerlayers of conventional needle-punched nonwovens. The outer layers from three types of raw materials (polypropylene, recycled polyester and mechanically recycled fibers) and the control groups were produced by classical needle-punching at two different needle-punch densities. Abrasion resistance and bending properties of the end products were investigated considering recycled layer ratio, raw material type and needle-punching density through standard test methods. Among all types, the highest abrasion cycles and bending rigidity values were observed for the PP outer layered products. Increase in needling density increased the abrasion cycles between 10%-20% and increased bending rigidity 3%-8% among the overall. Comparing the fabrics with recycled layer of 20% to control groups, abrasion resistance was preserved between 67% -75% and bending rigidity was preserved between 86%-93% at overall.

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KEYWORDS

Recycling, needlepunched nonwovens, abrasion resistance, bending rigidity

INTRODUCTION

Effective utilization of limited resources gains importance in terms of sustainability in all areas of production with the increase in population and the widespread use of fast consumption throughout the world in recent years. When environmental awareness and economic factors are evaluated together, it is seen that investigations on recycling issues become attractive for the researchers in the textile sector as in other sectors.

Recycling can be defined as the utilization of waste materials as raw materials to be used in new products [1]. Recycled fibres can be used as raw materials for high consumption and value added products [2]. This concept is evaluated in two classes as open loop and closed loop recycling according to the production flow of the new product to be obtained by recycling the waste material [3]. In the openloop system, which is widely used in textiles, the material is not recycled repeatedly and it is used to be evaluated in a relatively low quality product. In closed-loop recycling, the material is recycled repeatedly and included in the production line. Both methods are very important for the sustainable textile industry. Textile waste can be evaluated in two groups as pre-consumer and post-consumer waste [4]. In the evaluation of waste, the size, types of waste and the production technology that it can be utilized are important. From this aspect needlepunched nonwoven production technology provides convenience in terms of waste recycling. Since preparation and production steps in nonwovens are relatively much more time saving and cost effective compared to weaving and knitting, it is a preferred way of gaining recycled textile structures. Nonwovens have been widely used for industrial applications such as filtering, geotextiles, insulation applications. Recycled nonwovens are examined by researchers considering their mechanical properties including abrasion resitance and bending properties. Sabry et

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al.(2020), studied on usability of rPET fibers in comparison with virgin PET. They investigated abrasion resistance performances of woven fabrics consisting of rPET and virgin PET fibers. As they expressed in their study, abrasion is one of the most important mechanical properties in textiles and recycled polyester fibers could be used blended with virgin PET fibers without noticeable changes in abrasion performances of fabrics. [5]. Midha (2011), studied with hollow polyester fiber and produced different types of specimens by calendering and sandwiching processes. The researcher investigated the influence of operation parameters on fabric stiffness and abrasion resistance of needlepunched nonwovens. In cocnlusion the researcher reported that abrasion performance of the specimens did not significantly affected by the operated range of needlepunch density and depth of penetration. Besides, abrasion resistance of the fabrics got higher by calendering and sandwiching [6]. Sakthivel et al.(2012), invesitigated needlepunched jute nonwovens and chemical bonding reclaimed nonwoven products in their study. Researchers reported that abrasion test rseults were higher in percent of 10% at the chemical bonding reclaimed nonwoven products in comparison with needlepunched jute nonwovens [7]. Koç and Çinçik (2013), studied on abrasion resistance of polyester-viscose blended needlepunched nonwovens. Researchers produced nonwovens at five blend ratios, four mass per unit areas and three different needling denisties. They investigated the effect of fibre composition and production parameters on abrasion resistances of theese nonwovens. The researchers reported that as the polyester ratio got higher in the blends abrasion resistance of the nonwovens decreased and with the increasing mass per unit area abrasion resistance incresed. They observed that as the punch density increased abrasion resistance firstly increased but further decreased [8]. Sharma and Goel (2017), used recycled cotton and recycled polyester fibers in different blends. They obtained nonwoven fabrics at changing mass per unit area values from these blends. They carried out mechanical performance tests to the samples and reported that the best results for abrasion resistance were observed for the blend ratio of %30-%70 [9].Palak and Karagüzel

Kayaoğlu (2019), produced nonwovens by needlepunching method by using different types of polyester fibers blends. The reserachers studied on the abrasion resitance performances of the samples and they observed that fiber blend ratio, penetration depth and areal density factors have significant affect on abrasion resistances of the fabrics samples while punch density was found to be statitically insignificant on the abraison resistance performances of the fabric samples [10]. Atakan et al. (2020), used original and mechanically recycled PET (rPET) and bicomponent PET fibres. They produced nonwoven fabrics via needlepunching at different blends. They inevsigated the abrasion resitance performances of the fabrics and revealed out that fabrics composed of 85% rPET 15% bicomponent PET had almost equal performance in terms of both fiber loss and carpet appearances with carpets consisting of 80% PET -20% bicomponent PET [11]. Islam and Alam (2018), investigated some selected properties of needlepunched nonwovens consisting of sustainable fibers such as banana, bamboo and hemp blended with PP and PET. The researchers reported that bending properties of the bamboo/PET/PP products were much higher than that of others due to the compact structure [12]. Thilagavathi et al. (2010), produced three types of needlepunched nonwovensby blending bamboo, banana and jute with PP fibers. They investigated a series of physical properties including bending of the fabrics. According to the test results the researchers stated that bamboo/PP demosntrated the highest bending rigidity in comparison with the others [13].

As it can be seen in literature many different kinds of recycled fibers can be used in nonwoven production. Researchers mainly focus on investigating the influence of production and fiber blend parameters on mechanical performances of the nonwovens. They study on balancing the low cost and the best performance of the new recycled products. Therefore, economic and ecologic optimization can be provided on new recycled products in appriopriate applications.

For both environmental and economic reasons textile waste shoud be considered as a ready-to-use raw material. Many of the researchers interested in recycling, study on finding proper ways for gathering and classifying textile waste, life cycle assesment for sustainability, besides some of the reserchers examine economic challanges as well as advantages of textile waste management. Observations and development trials for effective recycling is continued by the researchers [15-22].

Turkey Union of Chambers and Commodity Exchanges issued Industrial Capacity Report Statistics of 2018 in January 2019. According to that report, recycling of the classified textile materials is recorded as the second most frequent fields of activity in Uşak [14]. When this large amount of production is taken into consideration, recycling of the trimmings generated during blanket production has an important share. Lengths of the trimmings arising from the shaving step in blanket production are too short for spinning so they are deposited in the waste section of the machine. Evaluation of these trimmings became the main purpose of this study because of the all concerning items mentioned above.

In this study it was aimed to recycle blanket trimmings through needlepunching and for this purpose blanket trimmings are used to constitute inner-layers for the end products. Since they have inevitable sizes to be used directly, they are blended with mechanically recycled fibers. To obtain the most appropriate recycled layer ratio preliminary production trials were carried out and the innerlayers are obtained by pre needle punching. Then the outer layers from polypropylene (PP), from recycled polyester (rPET) and from mechanically recycled fibers (MRF) in compatible mass per unit area values are produced by needle punching. The recycled innerlayers consisting of mechanically recycled fibers and blanket trimmings are then fixed by needle punching again, between the two twinlayers of needle-punched nonwovens of those three types of raw materials. Thereby, three layered end products are produced. It was aimed to produce multilayer nonwovens to be used for multifunctional purposes such as insulating materials (thermal insulation), membrane protective materials (protection against punching), packaging (wrapping) considering the recycled layer inside the end products the most appriopriate usage is trying to be assessed via standard test methods as an on going study. Abrasion and bending rigidity test were applied at this stage to observe the performances of the products in case of being used where these properties become crucial such as protective and packaging functions.

The abrasion resistance and bending rigidity of the end products are evaluated through standard test methods [23,24]. The results obtained are statistically analysed through SPSS 23 programme and invesigated in comparison with the control groups which do not include the recycled layer.

MATERIAL AND METHOD

Material

In this study polypropylene fibers (PP), mechanically-thermally recycled polyester fibers from PET bottles (rPET) and mechanically recycled fibers (MRF) were chosen as raw materials for the top and bottom layers of the three layered end products. Mechanically recycled fibers consist of different fiber types as a result of the process of mechanical recycling. For the innerlayers which is named as recycled layer (RL), blanket trimmings and mechanically recycled fibers were used in the blend ratio of 25%-75%. Blanket trimmings are mainly trimmed from acrylic blankets.

The properties of fibers used for the top and bottom layers are presented in Table 1. Recycled fibers were gained by mechanical recycling of any type of textiles consisting of various fibers with length values in rank of 6 mm-22 mm and fineness values changing between 6-12 dtex. Length values of the blanket trimmings were below 5 mm.

Method

The production processes were carried out at the firm KNG Nonwovens. Bales were opened up and an antistatic agent was applied to the fibers against static electric charging and held for 24 hours. Opened and dispersed fibers were fed in to the carding zone. The webs formed by carding were transferred to the cross lapper by doffer. Folding of the layers were adjusted to provide the mass per unit area values for each type of fabric and layered form of the webs were delivered to pre- needle punching passing through the web feeder. Firstly the top and bottom layers of PP, rPET and mechanically recycled (MRF) raw material were produced at 4 (for PP and rPET) and 3 (for MRF) mass per unit area values in terms of g/m^2. After that the innerlayers including blanket trimmings were produced through the same needle-punching process to be laid down between the top and bottom layers and to complete the mass per unit area of the end products to 500 g/m^2 for each type of the raw materials. Pre-needle punching loom used for this research was 12 cm x 240 cm in size and contained approximately 3600 needles vertically arranged. Needle type was 5 x 18 x 32 x 3 ½ R333 G 1002. Depth of needle penetration was kept constant at 11 mm. Production speed was kept to 3.67 meters/minute. Stroke frequency was arranged as 300 punches per minute. Number of needles in the unit width of needle-punching loom is calculated considering the total width of the needlepunching loom as 240 cm with 12 needle strokes of 3600 needles.

Considering these production parameters punch densities of the fabrics were calculated through the equation given below where;

Table 1. The properties of PP and rPET fibers used in the study

Fiber Type	Fibre Length (mm)	Fiber Fineness (dtex)	Fibre Tensile Strength (cN/tex)	Fiber Elongation (%)	Fiber Crimp (per cm)	Cross Section
PP	64	6.67	4.31	92%	6	
rPET	64	6.67	3.50	78.6%	4	

$$E_d = \frac{n_h \cdot N_D}{V_v \cdot 10^4} \quad (1)$$

E_d ,is stitches per area (cm^{-2}),

n_h, is number of lifts (min^{-1}),

N_D, is number of needles by m working width (m^{-1})

V_v, is web outlet speed ($m.min^{-1}$).

Needle-punch densities of the nonwoven fabrics were calculated through this formulation as indicated below and found to be 12 punches/cm^2 for each type of nonwoven fabric which can be considered as a soft pre-needle punching process.

Laying down of the innerlayers between the top and bottom layers was held by hand and then the three layered structure was fed into preneedle-punching loom with the same production adjustments to obtain end products of the first needle-punching density. Thereafter the equivalent part of the end products obtained at first needle-punching density value was fed in to the main needle-punching loom in the sizes of 46 cm x 240 cm and containing approximately 22000 vertically arranged needles. By using the same adjustments at the first producing process end products of the second needle-punching density were obtained. Properties of the 28 types of fabrics produced for the study are presented in Table 2.

Abrasion Resistance Test

The resistance of a fabric to abrasion resulting from the friction movement on a certain surface is expressed as the abrasion resistance of that fabric. During the abrasion resistance test, fabric samples are exposed to friction under a certain pressure. In determining the abrasion resistance of the samples obtained within the scope of the study, ISO 12947-2 standard was taken as basis [23]. The Martindale Abrasion and Pilling device shown below in Figure 1, which is available in the Physical Textile Testing Laboratory of Uşak University Textile Engineering Department was used in the application of the test.

Figure 1. Martindale Abrasion and Pilling Tester

Table 2. Caharcterization of the three layered end products Needlepunching Densities (I,II) (punches/cm^2

Raw material of the top and bottom layers	**Mass per unit area of the top and bottom layers(g/m^2)**	**Recycled material amount included in end product(g)**	**Ratio of recycled layer to the end product(%)**
	75	350	
PP/RL/PP	100	300	70
($500g/m^2$)	150	200	60
	200	100	40
	250	0	20
Control Goup			0
rPET/RL/rPET	75	350	70
($500g/m^2$)	100	300	60
	150	200	40
	200	100	20
Control Goup	250	0	0
MRF/RL/MRF	100	300	60
($500g/m^2$)	150	200	40
	200	100	20
Control Groups	250	0	0

Four samples each cut in 38 mm diameter in accordance with the standard were conditioned at 20 ° C ± 2 temperature and 65 ± 4% relative humidity for 24 hours. In the study, taking into account the mass per unit areas of the samples, a weight of 12 kPa was used in accordance with the standard. Abrasion of the fabrics occurred in the form of pilling of the outer surface, the loss of beads during the ongoing wear test and then the formation of holes in the fabric surface. The number of cycles at which the first hole with a diameter of 0.5 mm was formed on the surface of the fabric was determined and evaluated [25]. The average of the abrasion resistance test results applied as described for the 4 samples taken, the standard deviation and CV% values were calculated. Test results were analyzed through SPSS 23.0-One way ANOVA method assessing at the 0.05 significance level. The significances of parameter effects were evaluated considering p values. When p value was lower than 0.05 ($p<0.05$), the effect of the parameter on abrasion resistance was supposed to be significant. Homogenity of variance for the data was investigated by Levene statistics and variances were found to be homogenous. The effects of raw material type, recycled layer ratio and needle-punching density (grouped as "1" and "2" for each type of specimens) parameters were investigated on the abrasion resistance of the fabrics.

Bending Rigidity Test

For determination of bending rigidity, the device in the Physical Textile Testing Laboratory of Uşak University is used. The device is demonstrated below in figure 2. Test procedure is followed through the test standards TS EN ISO 9073-7." [24]. The specimens were cut in 2,5 cm x 25 cm dimensions of 6 pieces both in the machine and cross machine directions and they were conditioned for 24 hours at 20 ° C ± 2 temperature and 65 ± 4% relative humidity. By using the bending lengths obtained from the measurements, the bending stiffness values were found in accordance with the equation in the standard, and their averages and CV% values were calculated.

Figure 2. Bending length measurement device

The bending rigidity values were obtained by evaluating the bending length results according to the equation included in the standard and given below.

$$G = m \times C^3 \times 10^{-3} \qquad (2)$$

Where G is; Average bending rigidity per unit width (mN.cm) c is; Overall average bending length of the specimen (cm) m is: Mass per unit area of the specimen (g).

RESULTS AND DISCUSSION

In this study, abrasion resistances and bending properties of the nonwovens were evaluated considering recycled layer ratio, raw material type of the end products, and needlepunching density. Since the mass per unit area values of the end products were kept constant the effect of changing recycled layer ratio on the three types of outer layered nonwovens could be taken into account during the evaluation.

Abrasion Resistance Results

Among all three raw material groups, the highest abrasion cycles were observed in the end products consisting of PP outer layers. Besides, the difference between the abrasion resistance values of the products with the outer layer of PP fiber and the outer layer of rPET fiber in the end products was found to be statistically insignificant. The increase in needling density increased the abrasion cycles of the fabrics. In addition it was observed that the effect of needling density, mass per unit area and raw material type factors on abrasion resistance of nonwoven fabrics were statistically significant at 95% confidence interval as demonstrated below in Table 3.

Table 3. Analysis of variance for abrasion resistance results of nonwoven fabrics

Factor	F Value	Significance
Needling density	21,457	,000*
Raw Material Type	15,013	,000*
Mass Per Unit Area	50,443	,000*

*α=0,05

Effect of Recycled Layer Ratio

Recycled layer ratio is calculated by taking into account the weight of recycled layer As the recycled layer ratio increases in all fabric types, a decrease in the abrasion cycles has been observed. The end products containing the least amount (20%) of recycled layer of PP and rPET fibers at I. needling density, demonstrated a maintenance of 72% of abrasion resistance in terms of abrasion cycles compared to the reference products. For MRF outer layered end products at I. needling density maintaining abrasion resistance value was observed as 67 % between end products containing the least amount (20%) of recycled layer and control groups. When it comes to the end products at II. needling density in the end products containing the least amount (20%) of recycled layer of PP and rPET fibers 75% of abrasion resistance in terms of abrasion cycles was preserved compared to the reference products. For MRF outer layered end products at II. needling density the remaining ratio of abrasion resitance was observed as 73 % between end products containing the least amount (20%) of recycled layer and the control groups. To evaluate the fabrics from an aspect of the abrasion resistance that they could preserve in comparison with control gruops, when recycled layer ratio of the products were 40% and 60%, for all types of fabrics at I. and II. needling densities, the abrasion resistance could be kept at 40%-55% and 15%-38% respectively. Lastly when the recycled layer ratio of the end products was 70% the preserved abrasion resistance could be between 14%20% among PP and rPET oluter layered fabrics considering control groups. It should be taken into consideration that, as the mass per unit area of the end products were kept constant at 500 g/m^2, the increase in recycle layer ratio means the decrease mass per unit area values of outer layers. Abrasion resistance of the samples were affected by the fibre to fibre frictional forces. As the mass per unit area of the outer layer gets higher number of fibres in the cross section of the fabric increases. This situation results in higher abrasion resitance. In figure 3, abrasion cycles of the end products according to the raw materials of outer layers for I. and II. needling density are presented.

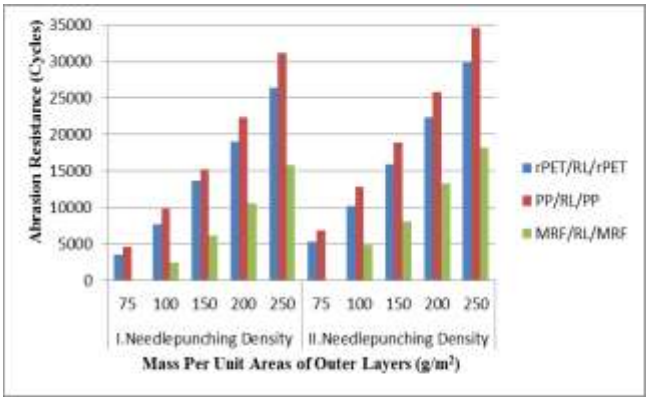

Figure 3. Abrasion resistance values of end products produced at I. and II needlepunching density

Effect of Raw Material Type of Outer Layers

Abrasion resistance results are obviously affected by the raw material type of outer layers. PP outer layered end products have the highest abrasion resistance results among all nonwovens produced in this study. This can be attributed to the originality and higher crimp level of the PP which affects the entanglement of the fibers with each other and also with the innerlayer As the crimped structure increases the contact points of the fibres, fibre to fibre frictional forces gets higher increasing the resistance to abrasion. The end products with rPET outer layers come second in abrasion resistance results due to the lower crimp of the rPET. rPET fibers are exposed to mechanical and thermal processes during the recycling steps. Hence, their crimp values and interaction between the fibres decrease resulting in relatively low abrasion resistance values at the end products. For the control groups that do not include the recycled innerlayers, abrasion resistance results are observed approximately 13%-16% in PP ones favour in comparison with rPET ones at overall. When it comes to evaluate MRF outer layered products, it is clearly seen that they have the lowest abrasion resistance values. In the mechanical opening processes, fibers are exposed to different types of cylinders coated with tooth-like structures. Therefore, a major mechanical damage takes place besides crimp losses and rubbish for individual fibers.

Effect of Punch Density

As the needling density increases, the fibers interlock with each other forming a more entanglened and tighter surface structure. This can be assumed as the main reason to explain the increase in abrasion resistance with the increase in needling density. When the control groups that do not include the recycled innerlayers, abrasion resistance results showed that there was an increase approximately 10% 13% as the needling density increased among all types of nonwovens. To evaluate the samples containing 20% recycled innerlayer with the least ratio, abrasion resistances of the PP and rPET outer layered samples changed in varity of 13% and 15% respectively. From the same aspect MRF outer layered samples demonstrated an increase approximately 20% when the needling density increased. This can be related with the unbonded regional parts of the MRF outer layers. These layers are composed of fibers that of partially lost their crimp due to the mechanical damages during recycling. This situation also causes a decrease in bonding of fibers to each other. Therefore, with the increase in needling denisty these parts of the outer layers are supposed to be entanglaned to the structure. The influence of needling density, mass per unit area and raw material factors on abrasion resistance of nonwoven fabrics was found to be statistically significant at 95% confidence interval.

Bending Rigidity Results

Bending behaviour is an important parameter to be assessed in nonwoven fabrics considering the applications in indusrtial fields. For instance, they can be used to protect surfaces from compressional forces and detection of their surface coating properties is related with bending behaviour. As Yılmaz et al.(2020), reported in their brief that the effect of the production parameters on bending properties of the nonwovens should be investigated further [26]. In this study the highest bending rigidity values were found in PP outer layered fabrics, while the lowest values were found in MRF outer layered fabrics. Due to the fiber orientation, the bending rigidity values of the samples in cross machine direction were found to be higher. It was observed that the increase needling density increases the bending rigidity of the fabrics for both machine and cross machine directions. As long as the needling density does not reach a level that will damage the fabric, it ensures that the fabric becomes tighter and the fibers are more intertwined. The increase in bending rigidity with the increase of needling density can be explained by this situation. It was observed that the effect of needling density, mass per unit area and raw material type factors on bending rigidity of nonwoven fabrics were statistically significant at 95% confidence interval as indicated below in Table 4.

Effect of Recycled Layer Ratio

When the bending rigidity results were evaluated from an aspect of recycled layer ratio of the end products, it was observed that in the machine and cross machine directions bending rigidity values were preserved in the ratio of 91% and 90% respectively in the products at I. needling density with PP outer layer and containing the least amount (20%) of recycled layer compared to the reference product made of PP fiber. When it comes to r PET outer layered end products at I. needling density the remaining ratio of bending rigidity was 93% and 91% for machine and cross machine directions in the end products having 20% reccyled layer ratio in comparison with the reference products. Lastly, 88% of bending rigidity was protected in both directions for MRF outer layared products at I. needling density in the same comparison conditions. When it comes to the end products at II. needling density PP and rPET outer layered end products containing the least amount of recycled layer with 20% demonstrated a maintenance of 91% and 92% in terms of bending rigidity compared to the reference products in both dircetions respectively. For MRF outer layered end products at II. needling density the kept ratio of bending rigidity was observed as 86 % and 89% between end products containing the least amount of recycling layer and control groups for machine and cross machine directions respectively. When the recycled layer ratio was 40%, bending rigidity for all types of fabrics at I. and II. needling density was preserved at the ratio of 72%-84% and 78%-86% in machine and cross machine directions respectively. At the recycled layer ratio of 60%, protected bending rigidity was 62%-72% and 61%-70% for machine and cross machine directions respectively compared to the control groups. Lastly when the recycled layer ratio of the end products was 70% the preserved bending rigidity could be between 55%-58% and 54%-60% among PP and rPET oluter layered fabrics considering control groups. Bending rigidity results of the end products for machine and cross machine directions can be followed below in Figure 4 and Figure 5 respectively.

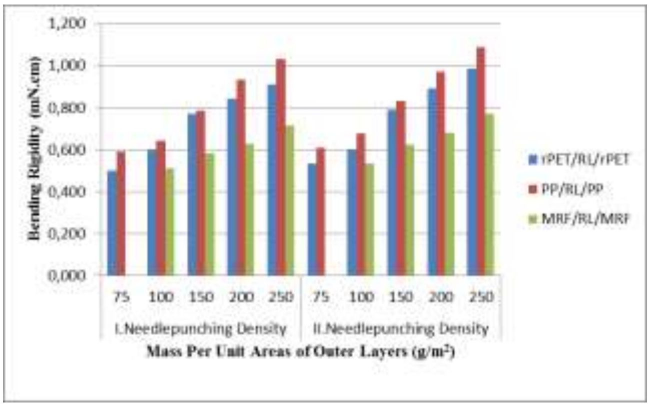

Figure 4. Bending rigidity of the products in machine direction

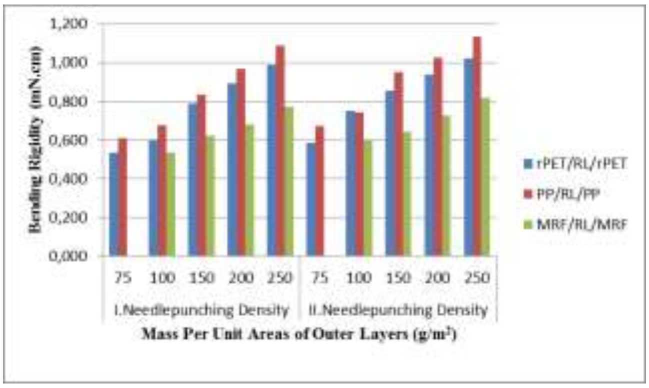

Figure 5. Bending rigidity of the products in cross machine direction

Table 4. Analysis of variance for bending rigidity results of nonwoven fabrics

Factor	F Value	Significance
Needling density	1004,211	,000*
Raw Material Type	465,342	,000*
Mass Per Unit Area	754,341	,000*

*α=0,05

Effect of Raw Material Type of Outer Layers

The highest bending rigidity values were observed in PP outer layered end products. Since PP fibers are light wight fibers in the polyolefin group, when PP fibers are used compared to products consisting of rPET fiber in the same weight, it will be possible to obtain products containing more fibers in the cross-sectional area. In this case, as a result of the entanglement of the fibers by passing through each other by needling, the products containing more connection points are those produced from PP fiber. Therefore, the high bending rigidity values of outer layer nonwoven fabrics made of PP fiber can be associated with this situation. The end products with rPET outer layers come second in bending rigidity values. Since they are mechanically and thermally processed during recycling, their crimp and adhesive properties decrease as expected. This causes a less stiffer structure than that of PP outer layered nonwovens. The lowest values were found in fabrics with outer layer of MRF. During the fabric opening processes, the fibers are exposed to deformation resulting in a dramatical decrease of surface friction and hence entanglement of the fibers. For the control groups that do not include the recycled innerlayers, bending rigidity results are observed approximately 10%-12% higher in PP outer layered products of I. and II. needling densities for both directions in comparison with rPET ones at overall. To evaluate MRF outer layered products, it is obviously found that they have the lowest bending resistance values as expected.

Effect of Punch Density

It was observed that the increase needling density increases the bending rigidity of the fabrics for both machine and cross machine directions. As long as the needling density does not reach a level that will damage the fabric, it ensures that the fabric becomes tighter and the fibers are more entanglened. The increase in bending rigidity with the increase of needling density can be explained by this situation. When the control groups that do not include the recycled innerlayers, bending rigidity results showed that there was an increase approximately 3% -8% as the needling density increased among all types of nonwovens for both machine and cross machine directions.

CONCLUSION

This study was carried out to examine the abrasion resistance and bending rigidity of nonwoven fabrics with recycled innerlayers. Both performance properties of the nonwoven fabrics were evaluated considering innerlayer ratio of the end products, raw material type of outer layers and needle-punching density. The data obtained from the test results were statistically analyzed in SPSS 23.0-One way ANOVA. In conclusion among all three raw material groups, the highest abrasion cycles were observed for the products in the PP outer layered nonwovens among all. When the fabrics containing the least amount of recycling layer (20%) were compared to control groups that do not include recycled layer, abrasion resistance was preserved between 67% -75% among all types of fabrics at I. and II. needlepunching densities. When recycled layer ratio of the products were 40% and 60%, for all types of fabrics at I. and II. needling densities, the abrasion resistance could be maintained at 40%-55% and 15%-38% respectively according to the control groups. Lastly when the recycled layer ratio of the end products was 70% the preserved abrasion resistance could be between 14%-20% among PP and rPET oluter layered fabrics considering control groups. The increase in needling density increased the abrasion cycles of the fabrics. This can be contributed to the tighter surface structure of the fabrics with increasing needling density. For the samples containing 20% recycled innerlayer with the least ratio the abrasion resistance cycles got higher between 10%-20% among overall fabrics. It was observed that the effect of needling density, mass per unit area and raw material type factors on abrasion resistance of nonwoven fabrics was statistically significant at 95% confidence interval.

Throughout the investigation on the bending rigidity values of the nonwoven fabrics the highest bending rigidity values were found in PP outer layered fabrics, while the lowest values were found in MRF outer layered ones. When the fabrics containing the least amount of recycling layer (20%) were compared to control groups that do not include recycled layer, abrasion resistance was preserved between 86% -93% among all types of fabrics at I. and II. needlepunching densities for both machine and cross machine directions. When the recycled layer ratio was 40%, bending rigidity for all types of fabrics at I. and II. needling density was preserved at the ratio of 72%-86% for overall fabrics in both directions. At the recycled layer ratio of 60%, protected bending rigidity was 61%-72% for both directions respectively compared to the control groups. Lastly when the recycled layer ratio of the end products was 70% the preserved bending rigidity could be between 54%-60% among PP and rPET oluter layered fabrics considering control groups. When the reference products that do not include the recycled innerlayers, bending rigidity results demonstrated that there was an increase approximately 3% -8% as the needling density increased among all types of nonwovens for both machine and cross machine directions. When bending rigidity results were statistically analyzed it was observed that the effect of all factors except direction of the specimen on the bending rigidity of fabrics was statistically significant at 95% confidence interval.

It can be concluded from this investigation that the nonwoven fabrics produced with appriopriate recycled layers considering economic and environmental benefits have promising abrasion resistance and bending rigidity performances.

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