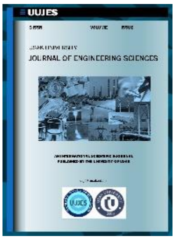

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Research article

AN INVESTIGATION ON RECYCLING OF BLANKET TRIMMINGS THROUGH NEEDLE-PUNCHED NONWOVENS

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Abstract

Utilization of recycled fibers in nonwovens has been an attractive issue for researchers considering environmental and economic benefits. In this study blanket trimmings and mechanically recycled fibers were blended and softly needle-punched to be used as interlayers of traditional needle-punched nonwovens. The outer layers from polypropylene, from recycled polyester, from mechanically recycled fibers and the control groups were produced by classical needle-punching at two needle-punch densities. The recycled interlayers consisting of blanket trimmings and mechanically recycled fibers are then fixed by needle-punching again, between the two twin layers of needle-punched nonwovens of those three types of raw materials. Control groups did not include the recycled interlayers. Hence, three layered end products were obtained. Tensile characteristics of the end products were evaluated in terms inter layer ratio of the end products, raw material type of outer layers and needle-punching density through standard test methods. The results were statistically analyzed in SPSS 23.0-One way ANOVA. In the conclusion, blanket trimmings were successfully entangled to the end products as interlayers and it was observed that the strength of the nonwovens decrease with the higher recycled interlayer ratio and increase with needle-punch density.

Keywords: *Recycling; blanket trimmings; nonwovens; needle punching; tensile strength; elongation.*

1. Introduction

Nowadays, increase in population growth and varying consumption habits in the world, depending on the developing technology, lead to a significant increase in industrial production and therefore in product consumption. Considering the economic and environmental factors, the evaluation of waste arising from both production processes and from consumer usage becomes very important for sustainability.

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Waste means all kinds of substances created during production processes or after consumer use, and which are inconvenient to leave directly or indirectly to the environment [1,2]. Disposal of the waste is inevitable for the producers since waste do not have direct benefit, and occupy space in the environment. Besides, the uncontrolled removal of waste leads to a complete loss of reuse potential and an environmental problem [3]. The studies on the evaluation of waste which occur in the textile field are mostly carried out for the treatment of chemical wastes and polluted water in the production processes, and it is understood that the scientific or practical studies related to the evaluation of solid wastes are one-way and limited.

Utilization of recycled fibers in nonwoven production technologies especially in needle-punching method has been commonly preferred by researchers for practicality and cost effectiveness. Since tensile properties of the end product is one of the major parameters for durability of the fabrics, regardless of the area in which the fabric will be used, researchers have studied on the assessment of mechanical strength and durability performances of nonwoven fabrics consisting of original and recycled fiber blends for several applications [4-20]. Radetic et al. (2003) worked on needle-punched nonwovens consisting of recycled wool and polyester fibers from the second hand knitted products. Tensile strength and absorption properties of the products were reported as a potential for suitable usage areas by the researchers [4]. Sakthivel et al. (2014) used 60% recycled cotton, 40% polyester fibers to produce nonwovens by needle-punching to be evaluated as automotive textiles. Through examination of the tensile strength of the recycled nonwovens before and after the calendering process, the researchers stated that these low cost fabrics depending on the areas of use, are sufficiently qualified for use as automotive textiles [5]. Kut and Orhan, (2004), used different blend ratios of recycled fibers to investigate the physical properties of nonwoven fabrics for flooring used in automobiles and homes. Although nonwovens produced in blend ratio of 50% original PP fibers, 50% recycled PP fibers are more advantageous in terms of total cost, especially for long-term use as flooring in cars and homes, nonwovens produced in blend ratio of 80% original PP fibers, 20% recycled PP fibers are found to be mechanically more strong and durable [6]. Sakthivel and Ramachandran (2012), in another study obtained cotton and polyester webs from mechanically recycled garment waste. They stated that the thermal conductivity values of the obtained structures vary depending on the type of recycle fiber, cotton polyester ratio in the structure and density values of the materials. They stated that recycling fiber additive significantly improves thermal insulation values [7]. Lin et al. (2010), stated that usage of polypropylene non-woven fabric waste together with polyester fiber and polyamide geogrid surfaces to obtain a laminated structure is a more environmentally benign method than the destruction of these waste [8]. Lin et al in another study (2015), used recycled Kevlar selvages in combination with crimped polyester (PET) fibers and and low-melting-point PET (LPET) fibers in 4 different blend ratios to produce needlepunched nonwoven fabrics. Increasing recycled Kevlar selvage ratio concluded in increase of tensile strength of the specimens [9]. Sharma and Goel (2017), used recycled cotton and recycled polyester fibers in three blend ratios of 30%-70%, 50%-50% ve 70%-30% in their study. They obtained needlepunched nonwoven fabrics in 3 different mass per unit area values and investigated mechanical properties including tensile strength. They reported that the highest values for tensile strength were observed at 30%-70% blend ratio specimen [10]. Wang et al. (2003), in another study for the evaluation of textile waste from the carpet waste worked on obtaining fiber bundles first by mechanical recycling method and according to the type of fiber forming carpets with the appropriate solvents in chemical way. The polymer fibers obtained as a result of this extraction are used as reinforcing materials [11]. Parikh et al. (2006) used cotton waste, kenaf fiber, jute, recycled polyester and substandard polypropylene fiber in different blend ratios to obtain needlepunched nonwovens in different mass per unit areas and investigated their usability for sound absorption applications [12]. Leon et al. (2016), used pre consumer and post consumer textile waste of polyester fibers. They used this blend in corporation with original PP in three different blend ratios forming needlepunched nonwoven fabrics to be used as geotextiles. Researchers investigated some of the mechanical properties of the fabrics. It is thought that one of these three mixtures will meet the geotextile structure properties targeted for optimum cost [13]. Gorchakova et al. (2013), reported that non-woven geotextile structures are commonly obtained by combining recycled polyester from PET bottle with different materials using thermal bonding, needlepunching and other methods. The researchers noted that the treatment of nonwoven fabrics obtained by needlepunching with organosilicon surface modification materials, improved the tensile strength by 25% [14]. Rawal and Anandjiwala (2007) have compared the properties of nonwoven geotextiles produced from polyester and linen fibers.It has been observed that the high variation in the fineness and length of the flax fiber as a natural feature can cause loss of strength in the final product [15]. Rawal and Saraswat (2011) examined the physical and mechanical properties of nonwoven geotextiles produced by PP, viscose and polyester (PET)-viscose (V) fiber blends produced by needlepunching method at two different mass per unit areas. For both mass per unit areas, the hybrid geotextile structure in the 60/40 PET / V mixture demonstrated the highest tensile strength value for the machine and cross machine directions [16]. Lin et al. (2014), produced needlepunched non-woven geotextiles of PET, kevlar waste and LPET fibers in the blend ratio of 60/20/20.They investigated effects of 3 different needle depth values on mechanical properties of non-woven fabrics obtained. With a slight the increase in needle depth they observed increasing values in mechanical properties including tensile strength [17]. Bulacu et al. (2015) compared the quality properties of needlepunched nonwoven geotextiles obtained by using recycled fibers made of PET material used for packaging purposes to the samples obtained from the original polyester and polypropylene blend in such a way that the processing conditions remain the same. The blend ratio was 80% r PET- 20% original PP for the first sample and 80% original PET-20% original PP for the second sample. When the tensile strength is examined from the performance characteristics of the samples, they stated that there is a negligible difference between the breaking load values of the samples in both blends. The tensile strength value in cross machine direction is 50% higher for both sample types than for the machine direction. In addition, the elongation at break values of the blends were found to be similar with each other. The researchers stated that the recycle fibers can be used as substitutes based on the proximity of the values obtained from the measurements [18]. In the study, Broda et al. (2016) designed innovative protective geotextiles and produced large and 12 cm thick ropes using waste fibers. The interior of these structures is filled with wool fibers, pieces cut from woolen nonwovens and shredded textile waste. The outer surface is in the form of a knitted sheath structure and is formed by using sisal and cotton strings [19]. In their study, Fangueiro et al. (2011), obtained needlepunched nonwoven fabrics using polypropylene, polyester and acrylic fibers in 5 different weights in order to examine the effect of mass per unit area on tensile and puncture strength they also realized the use of a 100% polypropylene plain woven reinforcing fabric to form a hybrid structure with nonwoven fabrics. When the results were examined, it was stated that the nonwoven surface increased the breaking and puncture strengths when the weight of the fabrics increased. The researchers also stated that the use of woven fabric as a second layer plays an improving role in the mechanical properties of the geotextiles considering the orientation of the fibers [20].

As can be seen in the literature, the researchers use recycled fibers in different blend ratios with original and various other fibers in needlepunched nonwovens to examine the performance characteristics of the resulting products. Thus, low-cost recycled products with values that can replace the original product in terms of usage performance are identified for appropriate applications.

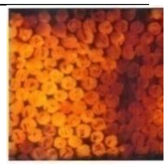
Textile sector has an important position on economical dynamics in Turkey in terms of production and exports. Tukey has been among the world's ranking exporters in textile and apparel sector. In the textile products manufacturing sector Uşak has been an emerging province on blanket production and recycling of textile materials. In Uşak, which has an 80% share in the production of blankets throughout the country, an average of 6 000 000 blankets are produced annually[21]. Besides An annual average of 570000 tons of textile waste is recycled [21]. Turkey Union of Chambers and Commodity Exchanges issued Industrial Capacity Report Statistics of 2018 in January 2019. According to these data, recycling of the classified textile materials is recorded as the second most frequent fields of activity in Uşak [22]. Considering this large production amount, recycling of the trimmings generated during blanket production has an important share. Since the dimensions of the trimmings that arise after the shaving step are not suitable for spinning, they are deposited in the waste section of the machine. These fibers, which can be probably used as filling material are baled by the producer and considered as "waste" to be disposed of. Precisely at this point the reasons such as depletion of natural resources, increase in the cost of waste disposal and reduction of storage areas bring out the necessity of evaluation of textile waste. Many organizations, including the Council for Textile Recycling (CTR), work to raise awareness of textile wastes and, by 2037, aim to ensure that there is no textile waste in landfills [23]. Textile waste is considered as a ready-to-use raw material and the re-evaluation is very important in terms of both environmental and economic aspects [3, 24-26].

In this study, blanket trimmings are blended with mechanically recycled fibers at the most appropriate rate obtained by trial and error against rubbish, and softly needle-punched so that they become interlayers for the end products. Then the outer layers from PP (at 4 different mass per unit area), from rPET (at 4 different mass per unit area), from mechanically recycled fibers (at 3 mass per unit area) are produced by classical needlepunching. The recycled layers consisting of mechanically recycled fibers and blanket trimmings are then fixed by needlepunching again, between the two twin layers of needle-punched nonwovens of those three types of raw materials. Hence, three layered end products were obtained. Layering of trimmings on nonwovens of different weights and different needling densities obtained from polypropylene, rPET, and mechanically recycled fibers, was performed by the help of mechanically recycled fibers and raising fluff as being carriers for trimmings. Thus, these fibers are recycled in a way that does not cause rubbish problem due to their size. By this way, blanket trimmings could be recycled despite their unfavourable size to spin or directly blend. The tensile properties of the end products are evaluated through standard methods to determine the usage performance [27]. The results obtained are statistically analysed an compared to control groups which does not contain the recycled layer to evaluate the effect of recycled layer on the tensile performances of the end products.

2. Experimental

In this study polypropylene fibers (PP), mechanically-thermally recycled polyester fibers (rPET) and mechanically recycled fibers (MRF) from several kinds of fabrics were chosen as raw materials for the top and bottom layers of the three layered end products. For the inter layers which is named as recycled layer (RL), blanket trimmings and mechanically recycled fibers were used in the blend ratio of 25%-75%. 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.

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

Fiber Type	Fiber Length (mm)	Fiber Fineness (dtex)	Fiber Tensile Strength (cN/tex)	Fiber Elongation(%)	Fiber Crimp Level (crimps /cm)	Fiber Cross Section
PP	64	6.67	4,31	92 %	6	
rPET	64	6.67	3,50	78.6 %	4	

2.1 Production Step of Nonwovens

Primarily the nonwovens to constitute the top and bottom layers of the end products of PP, rPET and raw materials were produced at four different mass per unit areas, and at three different mass per unit areas for mechanically recycled (MRF) raw material. Thereafter the interlayers containing 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/m2 for each type of the raw materials.

The needle-punched nonwoven fabrics were produced at KNG Nonwovens. Fibers opened up from the bales were applied an antistatic agent to prevent static electric charging and were laid out for 24 hours. Opened and dispersed fibers were fed in to the carding zone. The webs formed by this way on the card was removed from the card by doffer to the cross lapper. Folding of the layers were adjusted to meet 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.

2.2 Needlepunching Process

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 formula given below where;

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

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. Properties of fabrics which will be used as top and bottom layers of the end-products are illustrated in Table 2.

Table 2 Properties of fabrics which will be used as top and bottom layers of multi-layered end-products

Raw material of the top and bottom layers	Mass per unit area of the top and bottom layers (g/m²)	Pre-needle-punch density
PP	75	12 punches/cm²
	100	
	150	
	200	
	250	
rPET	75	
	100	
	150	
	200	
	250	
Mechanically recycled fiber	100	
	150	
	200	
	250	

The inter layers were laid down between the top and bottom layers by hand and then the three layered structure was fed into pre-needle-punching loom with the same production conditions to get end products of the first needle-punching density. Afterwards 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 3.

Table 3 Properties of the end products

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 end product (%)	Needle-punching densities I	Needle-punching densities II
rPET/RL/rPET ($500 g/m^2$)	75	350	70	48 punches/cm2	123 punches/cm2
	100	300	60		
	150	200	40		
	200	100	20		
	250	0	0		
PP/RL/PP ($500 g/m^2$)	75	350	70		
	100	300	60		
	150	200	40		
	200	100	20		
	250	0	0		
MRF/RL/MRF ($500 g/m^2$)	100	300	60		
	150	200	40		
	200	100	20		
	250	0	0		

3. Test Procedure and Statistical Evaluation

Nonwoven fabrics were determined through tensile strength and elongation at break tests via standard test methods [27]. Five measurements were held for tensile strength and elongation at break both in machine and cross machine directions. All the measurements were carried out under standard atmospheric conditions (20 ± 2 °C temperature and 65± 2% relative humidity).Test results were noted in terms of N for strength and % for elongation at break values. Since the thickness of the fabrics in non-woven fabrics significantly affect the physical performance characteristics tensile strength of the specimens were calculated through the formula below:

$$\sigma = \frac{F}{x.t} \tag{2}$$

where F represents maximum force at break (N), x: specimen width (mm) and t specimen thickness (mm). As a result, the load per section area was calculated as N / mm^2.

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 tensile and tear strengths 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, machine direction or cross machine direction of the specimens, recycled layer ratio and needle-punching density (grouped as “1” and “2” for each type of specimens) parameters were investigated on the performance test of the fabrics.

4. Results and Discussion

In this study, tensile strength and elongation at break values of the end products were examined considering recycled layer ratio since the mass per unit area values for the end products were kept constant. By this way the effect of recycled layer ratio on the three types of outer layered nonwovens could be taken into account during the evaluation. In addition to raw material type of the end products, direction of the specimen conducted to the test and needle-punching density parameters were investigated.

Results of the statistical analysis revealed out that, the effects of raw material type, machine direction or cross machine direction of the specimens, recycled layer ratio and needle-punching density significantly affects the tensile strength and elongation at break of the nonwovens. In addition, interactions of these parameters were found to have statistically significant effect on the tensile characteristics.

4.1 Tensile Strength

Effect of Recycled Layer Ratio

In figure 1. By giving the results according to the mass per unit areas of the outer layers of end products, the effect of recycled interlayer ratio is demonstrated since the end product mass per unit areas were kept constant at $500g/cm^2$. As the amount of recycled interlayer ratio gets higher and the mass per unit area of the outer layers gets lower, tensile strength results decrease as expected. For the end products with the outer layers of $150g/m^2$ and $200\ g/m^2$ (including the recycled interlayer at the ratio of 40% and 20% respectively) the tensile strength values of the end products at, containing 20% and 40% recycled interlayer were found to be between 10% and 35% lower in those with PP and rPET outer layers compared to the control groups overall the fabrics.

When the recycled interlayer ratio gets 60% and 70%, the tensile strength values of the PP and rPET outer layered end products were found to be between 50% and 90% lower than the control groups.

Although the overall tensile strength values of the end products with the outer layer of MRF were quite low, the tensile strength values of those containing 20% and 40% recycled interlayer were lower in the range of 10% -15% compared to the control groups on its own for. In the case of recycled interlayer ratio gets 60%, the tensile strength values of the MRF outer layered end products were found to be between 30% and 90% lower than the control groups.

Besides, it can be concluded from the Figure 2 that tensile strength results of the end products in cross machine direction are higher than that of machine direction. This is related to the cross lapping process causing more fiber orientation in cross direction.

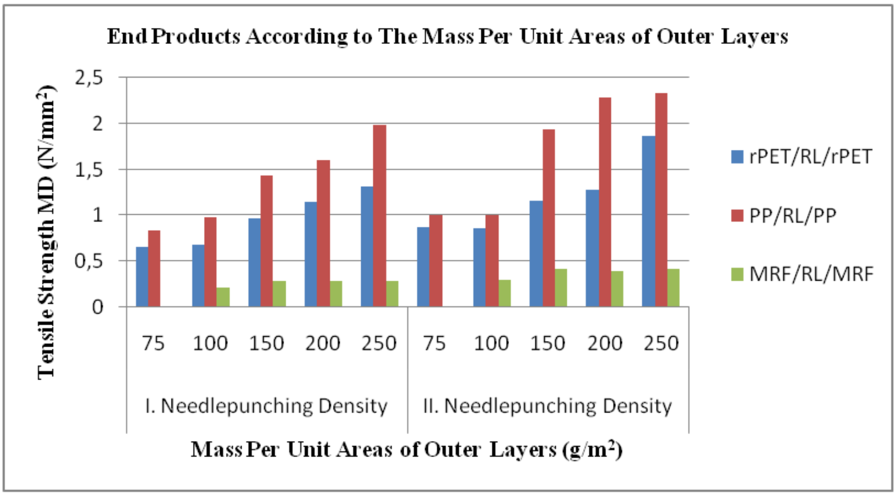


Fig.1 Tensile strength values of the end products produced at the I.and II. Needle-punching density for machine direction

Effect of Raw Material Type of Outer Layers

Tensile strength results are obviously affected by the raw material type of outer layers. PP outer layered end products have the highest tensile strength results for all nonwovens produced in this study. This is attributed to higher fiber tensile strength of the PP and also the higher fiber crimp value which affects the entanglement of the fibers with the interlayer. End products with rPET outer layers come second in tensile strength results due to the lower fiber tensile strength of the rPET. rPET fibers are exposed to mechanical and thermal processes during the recycling steps. Hence, their fiber tensile strength and crimp decrease resulting in relatively low tensile strength values at the end products. For the control groups that do not include the recycled interlayers, tensile strength results are observed approximately 10%-25% 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 tensile strength values. During the mechanical opening processes, fibers pass over several kinds of cylinders coated with different types of tooth-like structures. Therefore, a major mechanical damage occurs together with crimp losses and rubbish problem for individual fibers.

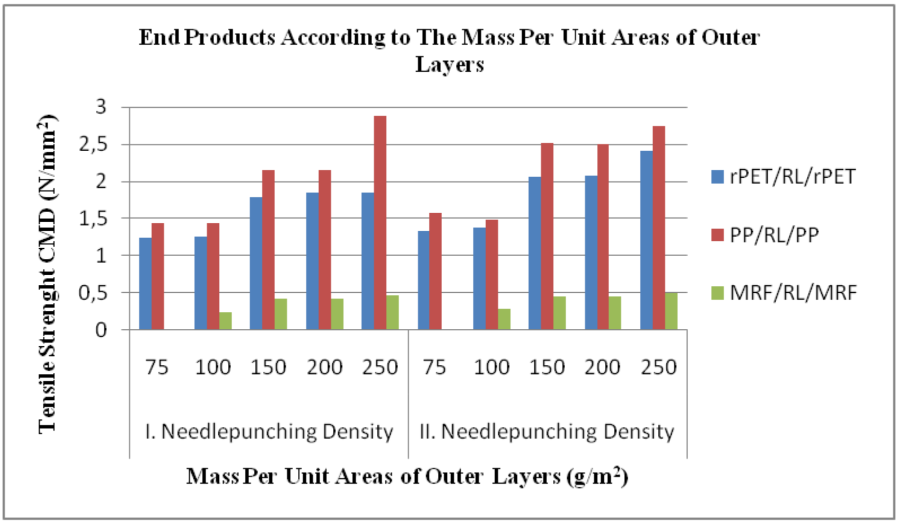


Fig. 2 Tensile strength values of the end productsproduced at the I.and II.needlepunchingdensity for cross machine direction

Effect of Punch Density

From Figure 1 and Figure 2 it can be observed that as the punch density increases, the tensile strength results of all the nonwovens increase for both machine direction and cross machine direction. Punch density is fundamentally related with the entanglement of the fibers in a web to form a nonwoven by needlepunching. Increasing punch density means the better and higher entanglement of the fibers. Therefore, tightness of the nonwoven gets higher and this results in higher tensile strength values.

4.2 Tensile Elongation

Effect of Recycled Layer Ratio

In Figure 3 elongation at break values of the end products are demonstrated. End products are classified according to the mass per unit area values of the outer layers. Thus, at the same time they can be evaluated considering the effect of recycled layer ratio since the mass per unit areas of the all products kept constant as mentioned above. The same tendency with tensile strength values are observed for elongation at break results. The elongation at break values of the end products at, containing 20% and 40% recycled interlayer were found to be between 10% and 50% lower in those with PP and rPET outer layers compared to the control groups overall the fabrics.

When the recycled interlayer ratio gets 60% and 70%, the elongation at break values of the PP and rPET outer layered end products were found to be between 47% and 71% lower than the control groups. Although the overall elongation at break values of the end products with the outer layer of MRF were quite low, the elongation at break values of those containing 20% and 40% recycled interlayer were lower in the range of 10 %-17%compared to the control groups on its own. In the case of recycled interlayer ratio gets 60%, the elongation at break values of the MRF outer layered end products were found to be between 20% -45% lower than the control groups.

In contrast to tensile strength results, the elongation at break in machine direction is higher than elongation at break in cross machine direction. Due to the cross lapping process fibers are majorly oriented in cross direction. Thus, fibers are in higher contact with each other and during the elongation test, fibers cannot pass over easily. This causes the elongation at break values in cross machine direction to be lower.

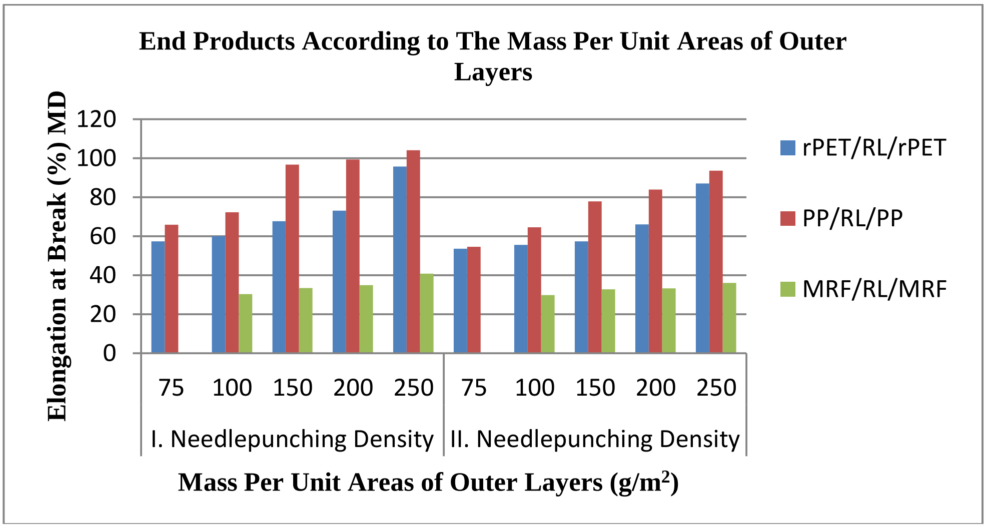


Fig. 3 Elongation at break values of end products produced at I. and II. needlepunching density for machine direction

Effect of Raw Material Type of Outer Layers

When the raw material type of outer layers at the end products are taken in to consideration; PP outer layered products demonstrated the highest elongation at break results overall the products. End products with rPET outer layers come second. For the control groups that do not include the recycled interlayers, elongation at break results are observed approximately 10% -25% in PP outer layered ones favor. When it comes to evaluate MRF outer layered products, it is clearly seen that they have the lowest elongation at break values owing to the results clarified above.

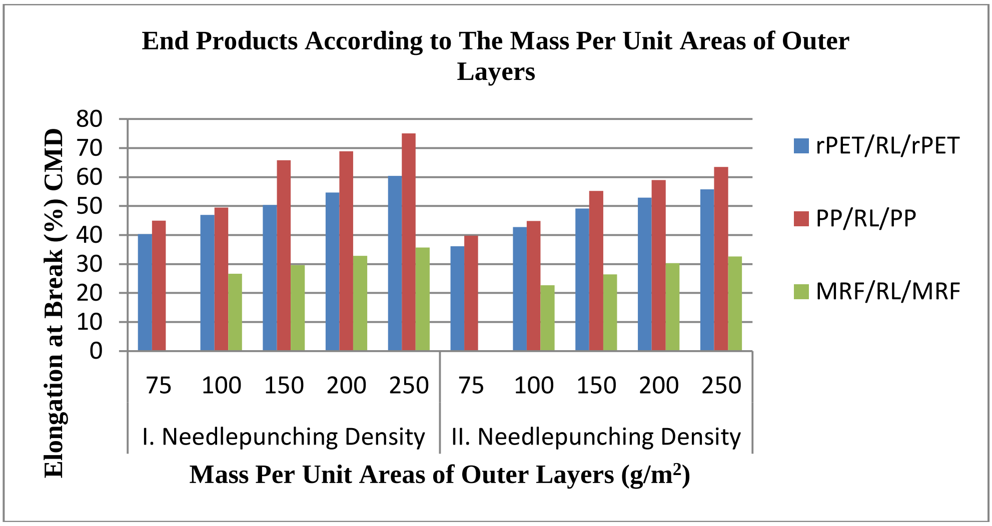


Fig. 4 Elongation at break values of end products produced at I. and II.needlepunching density for crossmachine direction

Effect of Punch Density

InFigure 3 and in Figure 4, as the punch density gets higher, elongation at break results decrease for both machine and cross machine directions. Fort he same groups of mass per per unit area values, increasing of the punch density causes more entanglement of the fibers and a tighter construction. This situation results in reducing of the fiber mobility and sliding over each other. Hence, elongation at break values decrease.

5. Conclusion

Tensile strength and elongation properties of the nonwovens produced in this study are significantly affected by recycled inter layer ratio of the end products, raw material type of outer layers and needle-punching density. According to the results obtained, as the recycled inter layer ratio increased general tensile strength and elongation results for all types of nonwovens decreased. It was observed that raw material type significantly affected the results. Due to the higher fiber tensile strength and crimp values of PP, tensile strength and elongation at break results of PP outer layer nonwovens were the highest overall the fabrics. Besides, with the rising of needle-punching density tensile strength results got higher in contrast to tensile elongation results. The results gathered in this study were found to be in consistent with the literature. It can be concluded that the nonwoven fabrics containing the recycled inter layer are capable of providing the expected performance characteristics according to the area of use by determining the appropriate usage conditions.

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