Physical properties of recycled PET non-woven fabrics for buildings

S Üstün Çetin¹ and A E Tayyar²
¹ Uşak University, Technical Sciences Vocational School, Uşak, Turkey
² Uşak University, Engineering Faculty, Textile Engineering Department, Uşak, Turkey

Email: sevcan.ustun@usak.edu.tr

Abstract: Recycled fibers have been commonly used in non-woven production technology for engineering applications such as textile engineering and civil engineering. Nonwovens including recycled fibers can be utilized in insulation, roofing and floor separation applications. In this study, physical performance properties such as drape, bending resistance, tensile strength, and breaking elongation values of non-woven fabrics consisting of v-PET (virgin) and r-PET (recycled) fibers in five different blend ratios are examined comparatively. The test results indicated that r-PET can be used in non-wovens for civil engineering applications such as insulation, roofing and floor separation fulfilling the acceptable quality level values.

1. Introduction
In recent years, recycling has been an attractive issue for researchers considering sustainability of the wastes arising from different engineering applications. In this scope, r-PET fibers which are mechanically and chemically recycled from PET bottles can be reused in needle punched non-woven production technology in profitable amounts. The first PET bottle recycling process made by the company, known as Jude Polymers, in 1976, by converting PET bottles into plastic belts and paint brushes [1]. It is known that 72% of the recycled PET flakes are used for fiber production [2]. In order to recycle PET and to be particularly suitable for secondary use, it is necessary to carry some physical properties. Otherwise, it is impossible for secondary usage. Some physical properties of recycled PET should have are listed in Table 1. Besides some researches indicated that 1 kg of PET sawdust from 1.246 kg of PET bottles by mechanical recycling and 1 kg of PET polymer of 1.133 kg of PET bottles by chemical recycling can be obtained [3].

Table 1 Properties of Recycled PET should carry [1].

| Property          | Value         |
|-------------------|---------------|
| $[\eta]$          | >0.7 dl g$^{-1}$ |
| Tm                | >240 °C       |
| Water Content     | <0.02 wt %    |
| Flake Size        | 0.4<D<8 mm    |
| Dyestuff content  | <10ppm        |
| Yellowing Index   | <20           |
| Metal Content     | <3ppm         |
| PVC Content       | <50ppm        |
| Polyolefin Content| <10ppm        |
Considering some application areas of r-PET, it is observed that fiber, yarn and fabric forms can be used respectively. Especially, morphological structures, common characteristics and differences in physical and chemical properties by changing production parameters of r-PET and v-PET fibers were investigated [4-5]. Many researchers have studied at different recycling methods, different spinning speeds and blend ratios of r-PET yarns to investigate their physical properties [6-8]. r-PET has been widely preferred to be used in denim fabrics, knitted fabrics and non-woven textile materials for its easy availability[9-11]. Other’s works and scientific reports have proved that plastic wastes and especially recycled PET may be applied for modifications of road pavement asphalt and also building concretes in construction industry [12-13]. The weight of a fabric covered with same area is about 1/30 of that of brick, steel or concrete. In this way, it has provided both less costs and less amount of reinforcement [14].

In this study non-woven fabrics made of v-PET (virgin) and r-PET (recycled) fibers in five different blend ratios are produced through a conventional needle punching system. Physical performance properties of these fabrics are examined by means of drapability, bending resistance, tensile strength, and breaking elongation tests. The test results are statistically evaluated in the SPSS programme.

2. Materials and methods

2.1. Materials

In the study, v-PET (virgin) and r-PET (recycled) fibers are used as raw materials for the non-woven fabric production. Before production, the length, fineness, and cross-sectional appearance of the fibers were examined. It is observed that the number of crimp of v-PET fibers, texturized, is twice the number of crimp r-PET which is not texturized and tensile strength of the r-PET fibers are approximately two times higher than those of v-PET. Structural properties of r-PET and v-PET fibers are presented in Table 2.

| Fiber Type | Crimp (1/cm) | Fiber Strength (cN/dtex) | CV Strength (%) | Breaking Extension (%) | CV Breaking Extension (%) | Fiber Fineness (dtex) | Fiber length (mm) |
|------------|--------------|--------------------------|-----------------|------------------------|--------------------------|---------------------|------------------|
| v-PET      | 4.2          | 3.39                     | 17.9            | 31.07                  | 19.1                     | 3                   | 60               |
| r-PET      | 2.2          | 5.06                     | 14.4            | 44.75                  | 25.22                    | 3                   | 60               |

2.2. Methods

In needlepunching process fibers are entangled through barbed needles during the strokes of needle loom. Five different blends of the afore-mentioned fibers have formed as follows: 100 % v-PET; 70% v-PET and 30 % r-PET; 50% v-PET and 50 % r-PET; 30 % v-PET and 70 % r-PET; and 100 % r-PET. Since blends consist of synthetic fibers, they are laid to rest for 24 hours after antistatic materials are applied to prevent electrification. Then non-woven fabrics using these blends have been produced in 6, 10, and 14 layers.

During production, fiber feeding direction, production speed, needle orientation and type are kept stable. Preliminary needling is carried out with 10 mm needling depth using 4000 needles at 150 rpm and the main needling is carried out with 3 mm needling depth using 40000 needles at 450 rpm. The speed of production is kept constant at 42 m/h.

Datum obtained from the different blends with same weights and same blend with different weights are examined. All fabric samples are conditioned at 20 ± 2 °C and 65 ± 2% relative humidity before they are subjected to the specified tests for at least 24 hours. The fabric thickness is determined...
based on TS 7128 EN ISO 5084 standard. The determination of the tensile strength is based on TS EN ISO 13934-1, "Stretching Properties of Textile-Fabrics-Part 1: The Strength of the Biggest Strength and the Strongest Strength under the Greatest Strength-Strip Method" standard. The determination of bending resistance and fabric weight are based on TS EN ISO 9073-7 "Determination of Bending Strength of Woven Textile Products" standard and “Determination of Unit Length and Unit Area Mass ISO 3801 Method 5 TS 251”, respectively [15-18].

3. Results

Thicknss, weight, drape, bending resistance and tensile strength tests have been carried out to evaluate the physical performances of these 15 fabrics. The mean values of results are demonstrated in Table 3. The effects of blending ratio on drape, bending resistance, tensile strength, and breaking elongation between groups according to the analysis of variance at 95% confidence level (p < 0.05) are listed in Table 3. The comparisons and differences among the groups for fabric type are performed using post-hoc Tukey and Games-Howell tests depending on homogeneity of variances. “a”, “b”, “c” and “d” letters are used in Table 3 to indicate the differences of measured average values of all type of fabrics.

Table 3 The mean value of results.

| Fabrics                   | Drape (%) | Bending Rigidity (mg.cm) (MD) | Bending Rigidity (mg.cm) (CD) | Tensile Strength(N) (MD) | Tensile Strength(N) (CD) | Breaking Elongation (mm)(MD) | Breaking Elongation (mm)(CD) |
|---------------------------|-----------|-------------------------------|------------------------------|--------------------------|--------------------------|----------------------------|----------------------------|
| 100% r-PET                | 92.94abc  | 257.52c                       | 289.88d                      | 70.14a                   | 142.69b                  | 16.04ab                    | 27.05a                     |
| 70% r-PET 30% v-PET       | 89.48abc  | 77.57a                        | 136.71a                      | 42.77b                   | 57.78a                   | 14.63ab                    | 28.53b                     |
| 50% r-PET 50% v-PET       | 91.96abc  | 81.16b                        | 162.56b                      | 25.15b                   | 39.35a                   | 18.77ab                    | 26.26a                     |
| 30% r-RET 70% v-PET       | 88.68abc  | 80.23a                        | 123.25a                      | 29.03ab                  | 35.13a                   | 14.92ab                    | 28.15a                     |
| 100% v-PET                | 9580      | 165.87b                       | 268.44c                      | 27.11ab                  | 46.10b                   | 15.14ab                    | 27.35a                     |
| 6 layer                   |           |                               |                              |                          |                          |                           |                            |
| 100% r-PET                | 97.59b    | 919.99c                       | 1439.12d                     | 177.99c                  | 448.54d                  | 11.77a                     | 21.64a                     |
| 70% r-PET 30% v-PET       | 96.2ab    | 542.6a                        | 1354.66b                     | 142.22b                  | 339.15c                  | 12.88ab                    | 24.37b                     |
| 50% r-PET 50% v-PET       | 96.55b    | 526.82b                       | 876.33a                      | 120.85b                  | 248.34b                  | 12.25ab                    | 26.82b                     |
| 30% r-RET 70% v-PET       | 95.92a    | 433.19a                       | 433.19a                      | 108.41a                  | 221.95a                  | 12.68ab                    | 25.53b                     |
| 100% v-PET                | 97.43a    | 1206.12d                      | 1430.15ed                    | 146.73b                  | 363.49d                  | 13.56b                     | 24.24b                     |
| 10 layer                  |           |                               |                              |                          |                          |                           |                            |
| 100% r-PET                | 98.76b    | 5162.70b                      | 4513.70b                     | 495.96c                  | 967.25b                  | 12.04a                     | 16.23a                     |
| 70% r-PET 30% v-PET       | 96.19a    | 2170.93a                      | 5246.32b                     | 397.45b                  | 803.17b                  | 11.55a                     | 17.67ab                    |
| 50% r-PET 50% v-PET       | 97.85b    | 1838.87a                      | 4158.49a                     | 301.70b                  | 514.95b                  | 12.05a                     | 18.59bc                    |
| 30% r-RET 70% v-PET       | 97.75b    | 2420.06a                      | 4357.54a                     | 247.00a                  | 465.52a                  | 11.18a                     | 20.71cd                    |
| 14 layer                  | 97.86d    | 9464.04c                      | 5797.81c                     | 296.91d                  | 380.77a                  | 13.77b                     | 21.14d                     |

Note: The average values are arranged such that the letter 'a' shows the lowest average value and the letter ‘c’ shows the highest average value. Any two average values not sharing a letter in common mean that they are significantly different from each other at 95% confidence level.

3.1 Weight and thickness

Increasing production layer from 6to 14under constant production circumstances has raised reasonably weight and thickness values of fabrics. Measured thickness and weight values and expected weight values of blended fabrics according to %100 fabrics showed in Table 4. Thickness and weight values of 100% v-PET and 100% r-PET fabrics are found to be fairly close. Considering the blended fabrics in three different ratios; thickness and weight values are measured as compatible with each other. However, measured weight values of blended fabrics are found to be much lower than expected weight values. It is considered that the difference between measured and expected weight values become husks. The percentage of husks changes between %19.81 and %31.86 and increases with the
higher percentage of r-PET amount. This is because of in capability of the stiff and non-texturized r-PET fibers to entangle and to locate in the structure. Losses of fibers affect the thickness values in the same manner.

Table 4 Weight and thickness value of results.

| Fabrics                  | Weight (g/m²) | Expected Weight (g/m²) | Observed Weight (g/m²) | Husks (%) | Thickness (mm) |
|--------------------------|---------------|------------------------|------------------------|-----------|----------------|
| 6 layer                  |               |                        |                        |           |                |
| 100% r-PET               | 165.08        | 165.08                 |                        | -         | 0.25           |
| 70% r-PET 30% v-PET      | 156.48        | 112.43                 | 28.15                  | 0.22      |                |
| 50% r-PET 50% v-PET      | 150.74        | 117.63                 | 21.96                  | 0.26      |                |
| 30% r-RET 70% v-PET      | 145.00        | 116.28                 | 19.81                  | 0.22      |                |
| 100% v-PET               | 136.40        | 136.40                 | -                      | 0.35      |                |
| 10 layer                 |               |                        |                        |           |                |
| 100% r-PET               | 308.83        | 308.83                 | -                      | 1.35      |                |
| 70% r-PET 30% v-PET      | 308.25        | 244.85                 | 20.57                  | 0.74      |                |
| 50% r-PET 50% v-PET      | 307.87        | 243.90                 | 20.78                  | 0.96      |                |
| 30% r-RET 70% v-PET      | 307.48        | 246.55                 | 19.82                  | 0.95      |                |
| 100% v-PET               | 306.90        | 306.90                 | -                      | 1.65      |                |
| 14 layer                 |               |                        |                        |           |                |
| 100% r-PET               | 540.10        | 540.10                 | -                      | 2.85      |                |
| 70% r-PET 30% v-PET      | 568.79        | 395.65                 | 30.44                  | 1.39      |                |
| 50% r-PET 50% v-PET      | 587.92        | 400.63                 | 31.86                  | 1.94      |                |
| 30% r-RET 70% v-PET      | 607.04        | 477.80                 | 21.29                  | 2.12      |                |
| 100% v-PET               | 635.73        | 635.73                 | -                      | 2.82      |                |

3.2 Drape
The increase in the number of layers has negative effect on the drape properties of all fabrics. The effects of blending ratio on the drape properties of all fabrics are statistically insignificant as shown in Figure 1 and Table 3.

Figure 1 Drape values of production groups.

3.3 Bending rigidity
Bending rigidity values of the fabrics in both machine direction and cross machine direction have been measured. The rising number of layers has reduced the bending ability of fabrics in both directions because of increase in weight and thickness values. The effects of blending ratio on the bending rigidity of fabrics in both directions are statistically insignificant as shown in Figure 2 and Table 3. The bending ability of all 100% fabrics are not crucially different. The bending rigidity of CD-fabrics of all layers are higher than that of MD-fabrics. This is probably because of cross layout of web.
3.4 Tensile strength and breaking elongation
Tensile strength of samples is tested in both machine direction and cross machine direction and results shown in Figure 3. The increase in the number of layers has positive effect on the tensile strength and negative effect on breaking elongation of all fabrics as shown in Table 3. The tensile strength of CD-fabrics of all layers are higher than that of MD-fabrics. This is probably because of cross layout of web and higher fiber orientation in cross machine direction. Conversely, the breaking elongations of CD-fabrics of all layers are lower than that of MD-fabrics. The tensile strength of 100% r-PET fabrics is higher than that of 100% v-PET fabrics because of higher fibers strength of r-PET. The breaking elongation all 100% fabrics are not different statistically. Although the effects of blending ratio on the tensile strength and breaking elongation of fabrics in both directions are statistically insignificant, higher r-PET ratio causes higher tensile strength and lower breaking elongation. Since, increasing the r-PET ratio added into blend leads to increment in husks amount thus, the effect of r-PET ratio on tensile properties is disguised.

4. Conclusions
The non-woven fabrics with 5 different blends of r-PET and v-PET fibers in 6, 10, and 14 layers have been produced. Weights, thickness, drape, bending resistance, tensile strength, and breaking elongation properties have been evaluated. As expected, ticker and heavier fabrics have less drape ability and breaking elongation while more bending rigidity and tensile strength. The effect of blending ratio on fabric properties can be seen more clearly if the amount of r-PET is increase by
about 24% in order to reduce husks. r-PET non-woven fabrics are competitive with ν-PET non-woven fabrics in many ways for construction industry where tensile and shape ability properties are necessary.

Acknowledgements
This work was supported by the Uşak University Scientific Research Project under grant [2010/TP009]. We would like to acknowledge the Department of Textile Engineering of Dokuz Eylül University for their technical support.

References
[1] Sevencan F and Vaizoğlu S A 2007 PET ve geri dönüşümü Kor Hek 6 (4) pp 307-312
[2] Shen L, Worrell E and Patel M K 2010 Open-loop recycling: A LCA case study of PET bottle-to-fiber recycling Resources, Conservation and Recycling 55 (1) pp 34-52
[3] Masaiko H. 2005. LCA as A Component of Configuration Engine for KII.
[4] He S-S, We M-Y, Liu M-H and Xue W-L. 2014 Characterization of virgin and recycled poly (ethylene terephthalate) (PET) fibers Journal of the Textile Institute 106 pp 800-806
[5] Tapia-Pieazo C, Luna-Bárcenas J G, Garcia-Chávez A, Gonzalez-Nuñez R, Bonilla-Petriciolet A, and Alvarez-Castillo A 2014 Polyester Fiber Production Using Virgin and Recycled PET Fibers and Polymers 15 pp 547-552
[6] Lee S Y, Won J S, Yoo J J, Hahm W-G and Lee S G 2012 Physical Properties of Recycled Polyester Yarns According to Recycling Methods Textile Coloration and Finishing 24 pp 91-96
[7] Abbasi M, Mojtahedi M R M and Khosroshahi A 2007 Effect of spinning speed on the structure and physical properties of filament yarns produced from used PET bottles Appl Polym Sci 103 pp 3972-3975
[8] Telli A and Özdíl N 2013 Properties of the yarns produced from r-pet fibers and their blends Tekstil ve Konfeksiyon 23 pp 3-10
[9] Can MU. 2015 Tekstil doküntüsü içeren nonwoven kumaşların iç mimaride kullanılabilirliliği Thesis (M.Sc.) Istanbul Technical University Institute of Science and Technology
[10] Choi Y J and Kim S H 2015 Characterization of recycled polyethylene terephthalates and polyethylene terephthalate–nylon6 blend knitted fabrics Textile Research Journal 85-4 2015
[11] Telli A and BabaarslanO 2016 The effect of recycled fibers on the washing performance of denim fabrics 108 pp 812-820
[12] Rebeiz K S and Fowler DW1994 Recycled PET flexural properties of reinforced polyester concrete made with recycled PET Journal of Reinforced Plastics and Composites 13 pp 895-907
[13] Sulyman M, Haponiuk J, and Formela K 2016 Utilization of Recycled Polyethylene Terephthalate (PET) in Engineering Materials: A Review International Journal of Environmental Science and Development 7 pp 100-108
[14] KOZAK M 2010 Tekstil atıkların yapı malzemesi olarak kullanım alanlarının araştırılması Teknolojik Araştırmalar 6 pp 62-70
[15] Turkish Standard 1998 Textiles determination of thickness of textiles and textile products TS 7128 EN ISO 5084
[16] Turkish Standard 2002 Textiles-Tensile properties of fabrics- Part 1: Determination of maximum force and elongation at maximum force using the strip method TS EN ISO 13934-1
[17] Turkish Standard 1973 Stiffness determination of woven textiles TS 1409
[18] Turkish Standard 1991 Determination of Mass Per Unit Length and Mass Per Unit Area of Woven Fabrics ISO 3801 Method 5 TS 251