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RESEARCH ARTICLE

Investigation of effect of pre-consumer recycling acrylic fiber ratio on yarn and fabric properties

Esin Sarioğlu[*1], Serdar Saycan[2], Perihan Tekin[2], Halil Ibrahim Çelik[3], Hatice Kübra Kaynak[3]

[1]*Gaziantep University, Fine Arts Faculty, Textile and Fashion Design Department, Gaziantep, Türkiye*
[2]*Melike Tekstil San. ve Tic. A.Ş., Gaziantep, Türkiye*
[3]*Gaziantep University, Faculty of Engineering, Textile Engineering Department, Gaziantep, Türkiye*

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Abstract

Within the framework of the European Green Deal, a circular economy model was adopted. It is necessary to investigate the recycling possibilities of the wastes produced during the production of residual products. Wastes can be classified in the textile industry as fiber, yarn, fabric waste, and post-consumer waste of the product in terms of raw materials. Before consumer use, wastes produced from raw materials are known as pre-consumer wastes, and wastes produced after use are known as post-consumer wastes. Both pre-consumer and post-consumer wastes can be recycled and used at certain rates in the production of new textile products. In this way, the waste of textile products before and after use is recycled and contributes to the environmental ecology. This study covers the recycling of 100% acrylic yarn waste, which is pre-consumer waste, by mechanical method and reuse in acrylic yarn production. For this purpose, Ne 20/1 yarns were produced with the same production parameters by blending acrylic fiber recycled from waste yarn with acrylic virgin fiber at 20%, 30%, and 40% ratios. Furthermore, a sample was produced from virgin acrylic fiber for investigation. The tenacity, elongation, unevenness, IPI, and hairiness properties of these produced yarns were determined. Single jersey fabrics were produced by using these yarns in an SDL ATLAS sample knitting machine. Fabric weight, course per cm, wale per cm, air permeability, bursting strength, bursting height, and pilling properties were analyzed. Test results show that the blend ratio of recycled acrylic fiber has a significant effect on yarn properties. On the other hand, it was found that this parameter has no significant effect on fabric properties.

1. Introduction

Because of the European Green Deal agreement, the European Union (EU) declared the goal of reducing net greenhouse-gas emissions by 55% by 2030. So, the EU needs to reduce emissions both at home and beyond its borders. Cement, iron-steel, fertilizer, aluminum and energy industries are the most important industries in terms of carbon footprint effect. After previously mentioned five industries, the textile industry is one of the most important sectors because of its ecological effects. Textile manufacturing consists of different steps like fiber cultivating, spinning, weaving, knitting, nonwoven, wet processing, and ready-made products, all are causes different levels of environmental pollution [1]. Depending on the population growth of the world, the textile product and raw material demand also increase rapidly. Depending on the population growth of the world, the textile product and raw materials demand also increase rapidly. When the fiber consumption around the world was investigated, it has been seen that the share of oil-based fiber groups is the biggest portion within 62.1 %, cotton fiber has about 25.2 % share, wood-based regenerated fiber groups have about 6.4 % share, cellulosic and protein-based other fiber groups have about 5.1 % share, and wool has about 1.2 % share of whole fiber consumption [2]. While the growth of natural fibers requires a high amount of water, pesticide, and insecticides usage and causes a high load of toxicological effects on the environment, therefore the production of synthetic fibers needs more energy, thereby contributing to global warming as a result of harmful greenhouse gas emission [1]. The textile industry generates large amounts of waste with the potential for recycling. Textiles are at the bottom of the league in terms of recycling. While 80% of steel is recycled, 65% of paper and 30% of plastics, recycling of textiles stands at 15-20% [3]. Although many governments try to reduce textile waste around the world, a significant amount of textile waste is disposed of. It has been reported that, across Europe, 10% of the clothing waste is recycled and 8% is reused, the rest are landfilled (~57%) or incinerated (~25%) [4]. In the U.S., the recovery rate for textiles has been reported to be around 15-16% [5].

Acrylic fiber is one of the most commonly used synthetic fibers. The characteristics of acrylic fiber resemble wool in terms of bulkiness, warmth, handle, and appearance. Acrylic fiber has a wide application area in knitted sweaters, socks, blankets, carpets, etc. The waste created by the industry can be grouped into two categories such as; Pre-consumer waste and Post-consumer waste. Pre-consumer waste is a material that was disposed of before it was prepared for customer utilization Post-consumer material waste is disposed of because of wear or harm and regularly incorporates utilized or worn apparel, bed cloths, towels, and other buyer materials [6].

Corresponding Author: Esin Sarioğlu
E-mail: sarioglu@gantep.edu.tr

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In literature, some studies have been made to investigate the performance properties of yarns and fabrics from pre-consumer and post-consumer acrylic fiber. The performance of the recycled acrylic samples was compared with virgin acrylic fiber products. Demiroz Gun and Kuyucak have compared the performance of virgin and recycled acrylic fibers that are produced with covered and PBT elastic yarns. It was revealed that recycled acrylic fabrics have a higher thickness, pilling tendency, abrasion resistance, and course-wise extension than virgin acrylic fabric. On the other hand, it was determined that recycled acrylic fabrics have lower bursting strength than the corresponding virgin acrylic fabrics. It was stated that the highest bursting strength and the lowest pilling tendency results are obtained for the fabrics with the PBT yarn. The elastane yarn incorporation improved the abrasion resistance of both recycled and virgin acrylic fabrics [7]. Demiroz Gun and Songul have investigated the effect of waste source type on yarn unevenness and tensile performance properties. For this purpose, yarn samples were produced from recycled acrylic fibers obtained from three categories; acrylic-based tops, yarn, and fabric waste. It was revealed that the 100 % recycled acrylic yarn type produced from the tops waste type showed the lowest Cvm% results and the highest tenacity and breaking elongation results. It was concluded that acrylic tops, yarn, and fabric wastes have the potential to be used as sustainable and low-cost sources of raw material in the production of open yarns of acceptable quality [8].

In this study, pre-consumer acrylic yarn was recycled to produce virgin acrylic fiber blended yarn samples and single jersey knitted fabrics. Yarn and knitted fabric performance characteristics were determined and results were evaluated statistically using Minitab^{TM} package program at 95% confidence interval.

2. Materials and Methods

Pre-consumer recycled acrylic fiber (rPAN) was blended with virgin acrylic (PAN) fiber at different ratios with 40, 30 and 20 %. Ne 20/1 yarn samples were manufactured. Indeed, 100% PAN yarn was also produced to compare the difference between rPAN fiber blended yarns. Totally, 4 yarn samples were manufactured at the same production parameters. Yarn production parameters were set up as roving count Ne 0.8, spindle speed 14.500 rpm, and twist coefficient (α_e) 3.18. Single jersey knitted fabrics were also produced from these yarns at 3.5” gauge, 22 fein and one feeder SDL Atlas laboratory knitting machine at 20±2 rev/min production speed. Before tests, all yarn and knitted fabric samples were conditioned under standard laboratory conditions (20±2ºC and 65±4%). Applied tests and standard are illustrated in Table 1.

Table 1. Applied tests and standards.

Test Name and Standard	Procedure
BS EN ISO 2062- Textiles - Yarns from packages - Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester	500 mm gauge length and 5000 mm/min
ISO 16549-Textiles -Unevenness of textile strands-Capacitance method	400 m/min test speed all through 2.5 minutes
ISO 9237- Textiles — Determination of the permeability of fabrics to air	Test pressure drop of 100 Pa (20 cm^2 test area)
TS EN ISO 13938-2- Textiles- Bursting properties of fabrics- Part 2: Pneumatic method for determination of bursting strength and bursting distension	The pressure was increased until the test specimen burst under 7.3 cm^2 test area
ISO 12945-2-Textiles — Determination of fabric propensity to surface pilling, fuzzing or matting — Part 2: Modified Martindale method	Totally 4000 cycles, evaluation every 2000 cycles, and evaluation on standard photographs corresponding to different pilling grades

3. Results and Discussion

3.1. Yarn properties

Tenacity-elongation

The tenacity and elongation test results of yarn samples blended with virgin PAN and rPAN at different ratios are illustrated in Figure 1 and Figure 2, respectively. As seen in Figure 1, a decrease in tenacity was observed with the increase of the rPAN fiber blended ratio in the yarn. This is an expected result because mechanical recycling of acrylic yarn waste into fiber reduces fiber length and strength. As a result, the tenacity of the yarns produced using rPAN fiber is lower than that of virgin PAN. As illustrated in Figure 2, yarn break elongation values vary between 20 and 17% and it is seen that the yarn produced from the 100% PAN fiber has the highest elongation value. When the effect of blending ratio was examined, it was determined that elongation values decreased with increasing rPAN ratio.

Unevenness and imperfection index (IPI)

Yarn unevenness refers to a variation in yarn fineness. In Figure 3, a higher rPAN blend ratio caused the increasing effect of the unevenness of yarn samples negatively. The lowest unevenness value was determined as 100%PAN yarn. In addition, it was determined that the highest unevenness value was in the yarn with the highest 40% rPAN content. IPI value is expressed as the sum of thin places (-40%/km), thick places (+50/km) and neps (+200/km) values per km in yarn. When IPI values of yarn samples were taken into consideration, similar to unevenness results was observed. Here, it is seen that the properties of the fibers in the mechanical recycling process naturally affect the yarn evenness properties negatively.

Hairiness

When the hairiness values of the yarn samples were examined, it was determined that there was a gradual increase from 100% PAN yarn to 60% PAN/40%rPAN yarn. In other words, it was determined that the 60% PAN/40%rPAN yarn with the highest hairiness value was 13.84% higher than the 100%PAN yarn. However, it is seen that the hairiness values of 20% and 30% rPAN fiber content yarns are close to each other.

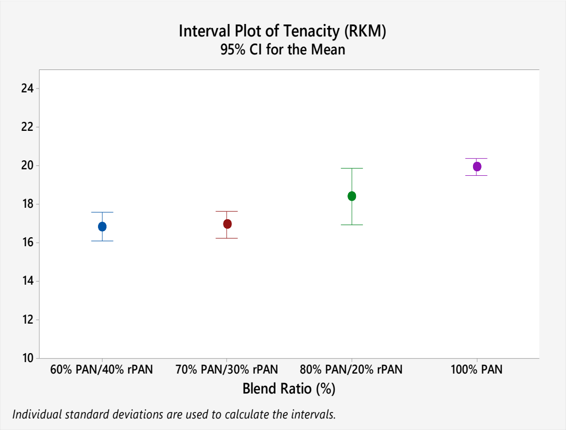


Figure 1. Tenacity results of yarn samples

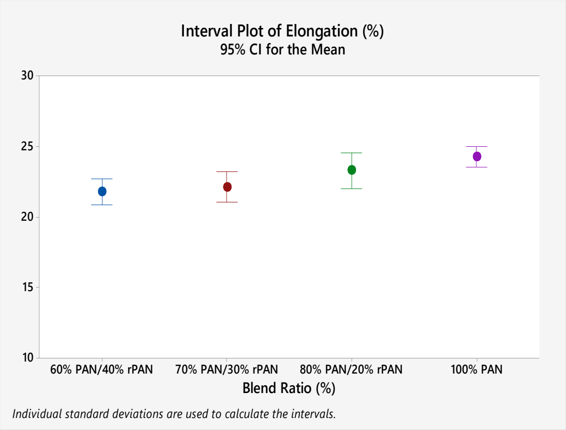


Figure 2. Elongation results of yarn samples

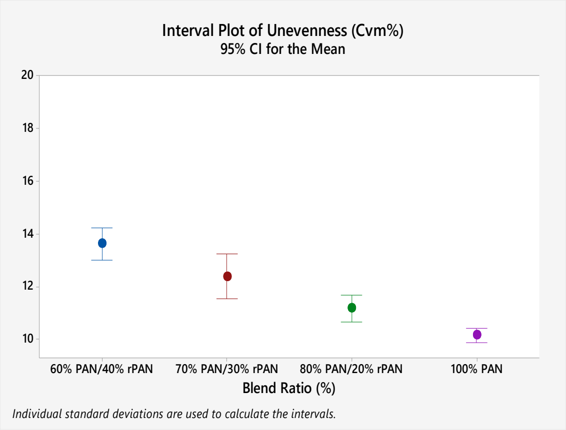


Figure 3. Unevenness results of yarn samples

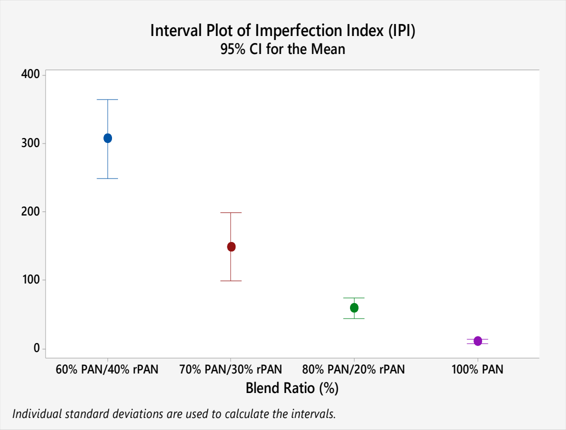


Figure 4. IPI results of yarn samples

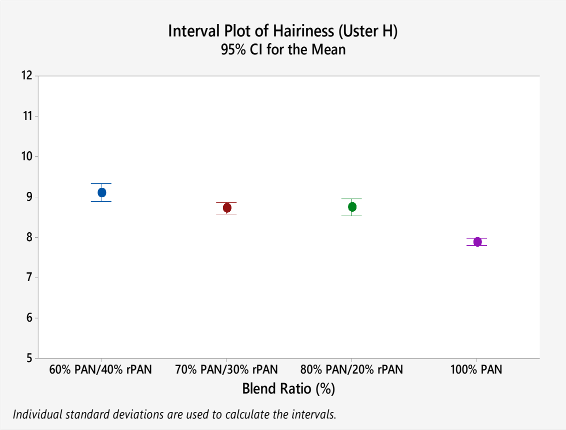


Figure 5. Unevenness results of yarn samples

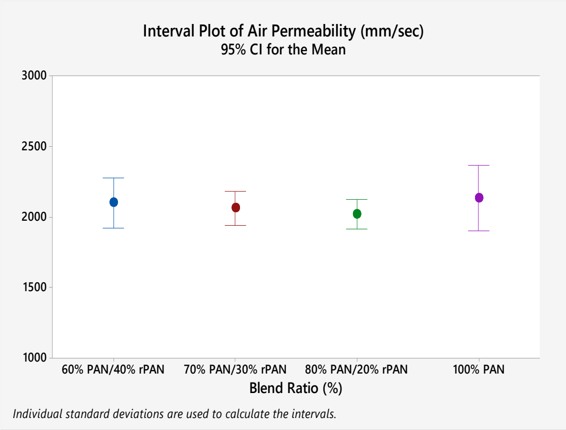


Figure 6. Air permeability results of yarn samples

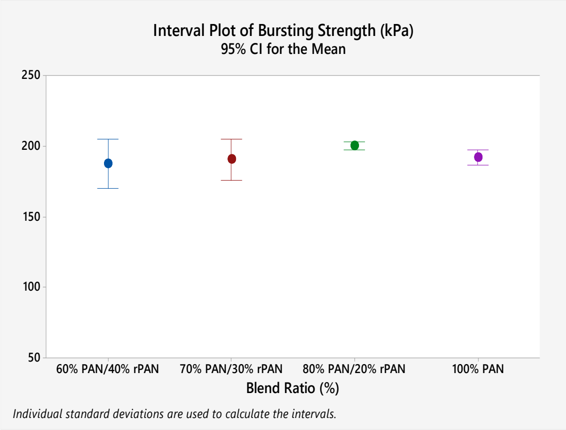


Figure 7. Bursting strength results of yarn samples

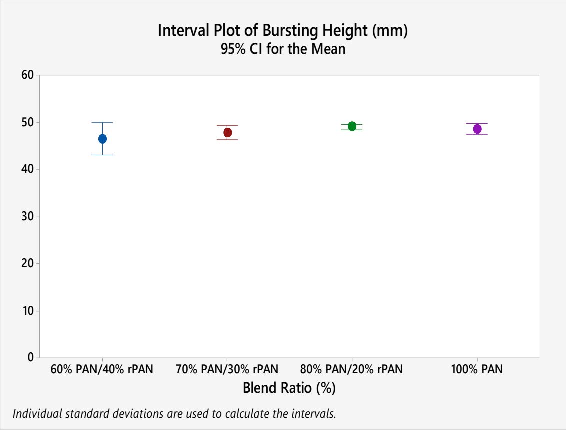
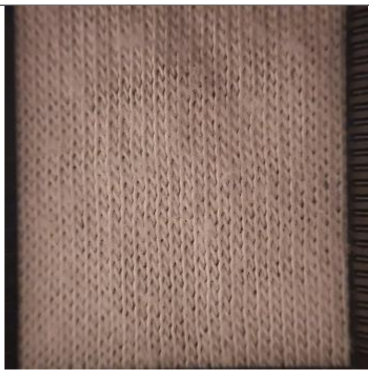


Figure 8. Bursting height results of yarn samples

Table 2. Structural properties of knitted fabrics.

Blend ratio (%)	WPC (wales per cm)	CPC (courses per cm)	Areal density (g/m^2)	Thickness (mm)
100% PAN	8	10	152	0.62
80% PAN/20% rPAN	8	10	142	0.65
70% PAN/30% rPAN	8	10	149	0.66
60% PAN/40% rPAN	8	10	160	0.65

Table 3. Pilling grade and visual photographs of knitted fabrics after 2000 and 4000 cycles

Blend ratio (%)	2000 cycle	4000 cycle
100%PAN	 *Grade 3-4*	 *Grade 2-3*
80% PAN/20% rPAN	 *Grade 2-3*	 *Grade 2*
70% PAN/30% rPAN	 *Grade 2-3*	 *Grade 2*
60% PAN/40% rPAN	 *Grade 2-3*	 *Grade 2*

3.2. Knitted fabric properties

Structural properties

The structural properties of single jersey knitted fabrics are submitted in Table 2.

Air permeability

Air permeability test results are shown in Figure 6. Air permeability is related to the void volume between yarns in the fabric structure and the void volume of the fiber in the yarn. In this study, the effect of blend ratio parameter on yarn and knitted fabrics produced from rPAN and PAN fiber was investigated. In this respect, it was determined that the air permeability values of the fabric samples were close to each other. It is seen in the Figure 6 that the blend ratio does not have a significant effect on air permeability.

Bursting strength-height

Strength measurements of knitted fabrics are determined as bursting strength. Bursting strength is determined by applying pressure in a given test area until the fabric bursts. At the pressure at which the fabric bursts, the bursting height is also determined. Here, bursting strength and bursting height are given in Figure 7 and Figure 8, respectively. When the bursting strength values were examined, it was determined that the results of the fabrics containing rPAN were close to each other. The same result was observed at bursting height. Contrary to the yarn tenacity results, it was determined that the rPAN blend ratio did not have an effect on the fabric bursting strength.

Pilling behavior

The pilling evaluation of the fabrics and visual photographs of after 2000 and 4000 cycles are given in Table 3. The pilling degree of single jersey knitted fabric produced from 100%PAN yarn was determined as grade 3-4 after 2000 cycles and 2-3 after 4000 cycles. It is seen that the pill formation is higher in rPAN-containing fabrics with different mixing ratios, without the effect of mixing ratio. In other words, it was determined that the pill degrees of the fabrics with 20, 30 and 40% rPAN content were similar.

3.3. Statistical analysis

As illustrated in Table 4, according to the ANOVA test results, blend ratio of rPAN fiber has statistically significant effect on yarn properties including tenacity, elongation, unevenness, IPI and hairiness at 0.05 level (p=0.000). On the contrary, it was determined that the blend ratio did not have a statistically significant effect on the fabric properties (p>0.05).

Table 4. ANOVA results of yarn and knitted fabric samples

	Source	DF	Adj SS	Adj MS	F-Value	P-Value
Tenacity (RKM)	Blend Ratio (%)	3	32.110	10.7032	19.34	0.000*
	Error	16	8.853	0.5533		
	Total	19	40.963			
Elongation (%)	Blend Ratio (%)	3	19.02	6.3406	9.30	0.001*
	Error	16	10.91	0.6816		
	Total	19	29.93			
Unevenness (Cvm%)	Blend Ratio (%)	3	33.655	11.2183	48.39	0.000*
	Error	16	3.709	0.2318		
	Total	19	37.364			
Imperfection index (IPI)	Blend Ratio (%)	3	254500	84833.2	85.80	0.000*
	Error	16	15819	988.7		
	Total	19	270319			
Hairiness (Uster H)	Blend Ratio (%)	3	4.0027	1.33422	66.07	0.000*
	Error	16	0.3231	0.02020		
	Total	19	4.3258			
Air permeability (mm/sec)	Blend Ratio (%)	3	36180	12060	0.67	0.581
	Error	16	286400	17900		
	Total	19	322580			
Bursting strength (kPa)	Blend Ratio (%)	3	453.0	151.01	1.68	0.210
	Error	16	1435.0	89.69		
	Total	19	1888.0			
Bursting height (mm)	Blend Ratio (%)	3	18.62	6.207	2.45	0.102
	Error	16	40.62	2.539		
	Total	19	59.24			

* Statistically significant at 0.05 level

4. Conclusion

This study includes yarn production from rPAN fibers obtained from mechanically recycled pre-consumer acrylic yarns at different mixing ratios. For this purpose, rPAN fiber was blended with PAN fiber at blend ratios of 20, 30 and 40%, and yarn was produced with the same production parameters. Then, single jersey knitted fabrics were produced from these yarns and both yarn and fabric properties were analyzed. The results obtained are summarized below:

- When the rPAN blend ratio increased, it had a negative effect on yarn strength and elongation values. However, when the yarn evenness and hairiness values were examined, it was determined that the Cvm, IPI and hairiness values of rPAN-containing yarns had higher values compared to 100% PAN yarn.

- Considering the fabric properties, it was concluded that the bursting strength, bursting height and air permeability values of knitted fabrics produced from yarns obtained from recycled pre-consumer acrylic yarns were similar. Moreover, it was determined that the fabric performance values obtained from PAN yarn were similar to other fabrics including rPAN fiber.
- It was observed that the pilling formation of rPAN-containing fabrics is higher than that of PAN knitted fabric.

Considering all these results, the use of recycled rPAN fibers from acrylic yarn in yarn production is very important in terms of both conservation of natural resources and reuse of textile wastes. Today, the use of recycled fibers by textile and fashion manufacturers in their products is of great importance for the implementation of the circular economy model. When the results of this study are examined, it is clear that the use of recycled fibers will become attractive in order to protect the nature, although the yarn properties with rPAN content are worse compared to PAN.

Author contributions

Esin Sarıoğlu: Writing-Original Draft, Methodology, Investigation, Data Curation, Visualization, Statistical Analysis, Writing, Review &Editing.

Serdar Saycan: Methodology, Conceptualization, Supervision, Funding acquisition.

Perihan Tekin: Methodology, Funding acquisition, Organization and Production of the samples, Testing.

Halil İbrahim Çelik: Investigation, Methodology, Data Curation, Writing, Review & Editing.

Hatice Kübra Kaynak: Literature Search, Data Curation, Visualization, Statistical Analysis, Review& Editing.

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