SUSTAINABLE POLYPROPYLENE FILAMENT YARN PRODUCTION FOR UPHOLSTERY FABRICS

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Abstract: *This study focuses on developing sustainable and cost-effective yarns for use in upholstery fabrics by incorporating recycled polypropylene. Polypropylene is widely used in textiles due to its low cost, easy processability and high strength. The research aimed to produce durable weft yarns with granules derived from polypropylene textile waste. Recycled and virgin polypropylene granules were used in the yarns with different blend ratios. The effects of blend ratio and yarn fineness on yarn breaking strength were also investigated statistically. Using similar parameters, it was found that up to 20% recycled polypropylene could be used without significantly affecting the strength of the yarn. While determining the yarn fineness, the fineness values that could be used in upholstery fabric production were considered and were determined to be usable especially in weft yarn. This study contributes to the home textile industry by supporting more environmentally friendly and economically sustainable production practices.*

Keywords: Polypropylene yarn, recycling, sustainability, tensile strength.

ODRŽIVA PROIZVODNJA POLIPROPILENSKE FILAMENTNE PREĐE ZA TAPACERSKE TKANINE

Apstrakt: *Ova studija se fokusira na razvoj održivih i isplativih prediva za upotrebu u tapacirskim tkaninama uključivanjem recikliranog polipropilena. Polipropilen se široko koristi u tekstilu zbog svoje niske cene, lake obrade i visoke čvrstoće. Cilj istraživanja bio je proizvodnja izdržljivih potkih prediva sa granulama dobijenim od otpada polipropilena. Reciklirane i neobrađene granule polipropilena korišćene su u predivi sa različitim odnosima mešanja. Uticaji odnosa mešanja i finoće prediva na čvrstoću pređe na kidanje takođe su statistički ispitani. Koristeći slične parametre, utvrđeno je da se može koristiti do 20% recikliranog polipropilena bez značajnog uticaja na čvrstoću pređe. Prilikom određivanja finoće prediva, razmatrane su vrednosti finoće koje bi se mogle koristiti u proizvodnji tapacirskih tkanina i utvrđeno je da su upotrebljive, posebno u potkovim predivima. Ova studija doprinosi industriji kućnog tekstila podržavajući ekološki prihvatljivije i ekonomski održivije proizvodne prakse.*

Ključne riječi: polipropilenska pređa, reciklaža, održivost, zatezna čvrstoća.

1. INTRODUCTION

Textile production involves many production processes that are most harmful to the environment. From obtaining natural or artificial raw materials to delivering them to the customer, it brings about negative environmental effects such as the use of large amounts of water, energy, chemicals and also the generation of large amounts of waste. The textile sector has become a priority in terms of sustainability today due to both its economic size and its impact on the environment. Today, the increase in environmental sensitivity and awareness of human health compared to the past has affected the textile sector along with all industrial branches. It is becoming increasingly important that textile products are produced in an ecologically sensitive manner, without harming the environment and human health, and using recycled fibers and yarns [1]. Reducing pesticides used in textile fiber production and preferring fiber productions with the least pesticide needs, reducing the use of chemical substances, paying attention to the use of recyclable materials or recycled fibers in the production and design phase of textile products, having a long product life and making product life cycle designs before production, applying cyclical rather than linear material flow and production methods, encouraging the reuse of textile products, establishing production systems that adopt waste reduction or zero waste strategies in textiles are very important in terms of sustainability in the sector. Encouraging the reuse of textiles that are environmentally valuable. However, this may not always be possible, and recycling strategies are of great importance at this point.

Waste management includes reducing the amount of waste, recycling the waste produced, preventing pollution and disposing of waste with appropriate technologies without harming the environment. Waste minimization is achieved by treating, storing or disposing of hazardous wastes generated during production and processes after production [2]. Textile products are constantly consumed in our daily lives, from bedding to towels, from clothes to upholstery fabrics, depending on the needs in textiles, ready-made clothing and home textiles and the changing fashion. Approximately 1 million tons of textile waste is generated every year in the world. The vast majority of this waste consists of textile waste generated in yarn and fabric production, fabric pieces generated during the apparel stage and used textile products. A large portion of this textile waste generated is recyclable [3]. Therefore, the development of recycling and waste processing strategies in textiles is very important. According to the Council for Textile Recycling, textile waste is divided into two groups: pre-consumer and post-consumer waste [4]. Pre-consumer textile waste is the waste generated during the production of all kinds of textile products. Textile waste generated during production is generally; waste originating from fiber manufacturing, waste originating from yarn manufacturing, waste originating from spinning the yarn and turning it into yarn form and waste originating from fabric manufacturing [5]. Post-consumer textile waste is textile products that are no longer needed by the user due to reasons such as wear and tear, being too small or out of fashion, and are discarded after their service life is over [3].

Some of the studies conducted on the use of recycled fibers and polypropylene yarns in the textile industry are summarized below: Aizenshtein and Efremov [6] have compiled a study on the importance of polypropylene fiber and yarn in the textile and technical textile industry, their areas of use, and annual production and consumption rates over the years they conducted their studies. Erdem et al. [7] provided information on the production methods of nanoparticle-added filaments and investigated the effects of some nanoparticles on polypropylene filaments. As a result of the study, it was stated that there was no significant change in the morphological and structural properties of nanocomposite PP filaments containing 0.3%, 1% and 3% nanoparticles. Wang [8] examined the recycling processes of carpets, which constitute a large part of textile waste. In addition, recycling technologies and processes were specified. Future changes, trends and needs were also mentioned. Yavaşçaoğlu [9] compiled information on waste, waste reduction and recycling in the production and usage processes of textiles. Prorokova et al. [10] focused on an easy and effective method to impart high chemical resistance to polypropylene yarns in their study. The method in the study is based on the formation of a very thin, continuous and even polytetrafluoroethylene coating on the surface of each filament-forming yarn. With this method, the potential to reduce material consumption and cost of fibers and yarns with high chemical resistance was indicated. Çelik [11] examined the usability and physical properties of polypropylene fiber in woven fabrics. It was stated that tearing and tensile strengths are high in polypropylene fiber woven structures, and moisture absorption is low compared to cotton and viscose fibers. Yakut et al.[12] aimed to develop an artificial neural network (ANN) algorithm that determines the crimp and brightness properties of PP yarns and the quantitative or categorical values of production parameters by changing the BCF production parameters of BCF polypropylene yarns used in machine carpet production. In the study, the ANN algorithm was able to obtain outputs quickly and reliably as a result of the evaluation of categorical and numerical data. Sözcü [13] recycled polypropylene yarn and carpet waste to produce PP yarn and applied mechanical yarn tests to these yarns. Afterwards, the recycled PP yarns produced were used on the carpet surface and the effect of PP yarns on the carpet was investigated. Rokbi et al. [14] investigated the effects of different temperature and pressure process parameters on the tensile properties of recycled polypropylene composite reinforced with plain woven jute fabric in order to increase the usage areas of recycled polypropylene and contribute to sustainability. In the study, eight different composite laminates were produced under varying pressure and temperature and it was determined that they had similar fiber weight ratios of up to 62%. Prorokova and Vavilova [15] applied coating process to polypropylene yarns in order to provide antimicrobial properties, reduce electrical resistance, increase strength and provide high chemical resistance. The process was carried out during the melt drawing process. In the study, it was stated that the coating was added with magnetite nanoparticles with strong antimicrobial activity and electrical conductivity, provided barrier antimicrobial properties to the yarn and reduced surface electrical resistance. Dönmez and Kebeli [16] obtained recycled PP granules from polypropylene-based nonwoven fabric wastes in their studies. Spunbond fabric production was carried out by mixing the produced recycled granules with the virgin granules at different ratios. When the strength properties of spunbond fabrics obtained from granule mixtures with different MFI (melt flow index) values were examined, it was stated that their tensile strength decreased when the recycled granule usage rate increased. Saleem et al. [17] studied the environmental impacts of plastic granules recycled from polyolefin-based plastic waste using the life cycle assessment (LCA) method. The research specifically evaluated the effects of the recovery rates of xylene used as a solvent on the environmental footprint. Lukoschek et al [18] discuss how melt spinning can be used to recycled polypropylene obtained from post-consumer waste to produce high-quality monofilaments. The aim of the study is to recycle waste polypropylene and produce sustainable, high-quality monofilaments. Frankenbach et al. [19] investigated the usability of mechanically recycled polypropylene from post-consumer sources in the production of multifilament yarns and the contributions of this process to the circular economy in the textile sector. As a result of the study, it was stated that recycled polypropylene can be successfully used in the production of multifilament yarns with appropriate process parameters and the mechanical properties of recycled polypropylene are sufficient for certain applications.

When the literature is examined, it is seen that there are not many studies on the use of recycled PP (r-PP) polymers in the textile sector and that this area is open to study. Polypropylene fibers are preferred in carpet and rug production due to their lightness, color fastness and stain resistance; in upholstery fabrics and curtains due to their moisture and mold resistance; and in pillow and blanket fillings due to their lightness and cost advantages. In particular, their low cost, easy processability, low density, high strength and high chemical resistance are the reasons why this polymer is preferred in the textile sector [7]. In this study, filament yarn production was carried out by using recycled polypropylene granules containing polypropylene-based textile wastes (polypropylene yarn waste, carpet waste, nonwoven surfaces, etc.) and virgin polypropylene in different blend ratios. Strength tests were applied to determine the breaking strengths of the yarns produced in different blend ratios and it was aimed to make evaluations about the breaking strength properties of these yarns and their usability in the upholstery sector. With the use of r-PP polymers in textile structures, product life cycles will be extended, more sustainable products will be obtained and production costs will decrease. In addition, the study is expected to contribute especially to the home textile sector. Because polypropylene yarn is preferred in the sector, especially in carpet production, upholstery fabrics, bedding fabrics and wall coverings. It has been evaluated that the recycled polypropylene yarns to be produced can be included in upholstery fabric structures, especially for future studies.

2. MATERIAL AND METHOD

In the experimental study, firstly virgin polypropylene (v-PP) and recycled (r-PP) granules containing polypropylene raw material carpet waste and yarn waste were subjected to MFI (melt flow index) test. The MFI test determines how much the melted plastic extends in a certain period of time under a certain temperature and load. This test is very important in terms of fluidity and viscosity control, especially in continuous and precise shaping processes such as fiber drawing. In the study, the flow of the material in both samples at 230˚C, under a load of 2.16 kg, in 10 minutes was determined according to the ASTM

D1238 standard [20]. In addition, DSC (Differential Scanning Calorimetry) analysis was applied according to ISO 11357-3:2018 standard [21]. This analysis was carried out to determine the important thermal properties of polypropylene granules such as crystallization temperature and melting enthalpy before yarn production. Afterwards, using the melt spinning method, FDY (fully drawn yarn) yarns containing recycled and virgin PP in different blend ratios were produced. The melt-drawn method is the easiest fiber drawing method to apply. The polymer is melted, and by applying pressure with the help of a pump, it is pressed into the spinneret at a constant speed. Afterwards, the fibers that encounter cold air solidify and prevent them from sticking together. The number and shape of the filaments in the yarns vary according to the number and structure of the spinneret holes. Since the amorphous region ratio of the obtained fibers is high, they do not have sufficient strength, therefore, stretching-drawing processes are also applied to increase the strength and crystalline region ratio. FET100 brand laboratory type melt spinning machine was used as shown in Figure 1.

Figure 1: Melt-Spinning Machine

The diameter of the nozzle holes in the machine is 0.4 mm and the nozzle hole height is 1.6 mm. The production parameters of the machine are shown in Table 1.

Table 1: Production parameters of filament yarns

Extruder parameters	Zone-1 Temperature	195˚C
	Zone-2 Temperature	210˚C
	Zone-3 Temperature	220˚C
	Zone-4 Temperature	235˚C
	Extruder Speed	15.1 rpm
	Extruder Pressure	60 bar
	Pump Speed	14 rpm
Drawing unit parameters	Godet-1 Speed	300 mpm
	Godet-2 Speed	500 mpm
	Godet-3 Speed	600 mpm
	Winder Speed	610 mpm

Filament yarn production was carried out by using recycled (r-PP) granules in 2 different ratios. All yarns were produced in a fixed fineness of 175 denier / 36 filament centerless. Table 2 shows the production plan of filament yarns.

Table 2: Properties of filament yarns

Yarn Code	r-PP / v-PP blend ratio (%)	Yarn fineness (denier)	Cross-sectional area of yarn
1	0 / 100	175 denier / 36 filament	Round
2	10 / 90	175 denier / 36 filament	Round
3	20 / 80	175 denier / 36 filament	Round
4	30 / 70	175 denier / 36 filament	Round

According to the yarn production plan in Table 2, the production of filament yarns with r-PP / v-PP blend ratio of 30 / 70 could not be done. The increase in the r-PP ratio above 20% and the increase in the recycled polypropylene granule ratio caused the material to break during fiber drawing and the production of yarn number 4 could not be done successfully. Air jet texturing process was applied to the produced filament yarns and the fineness determination of the yarns produced was done according to the TS 244 EN ISO 2060 standard [22]. All yarns are 175 denier fineness as seen in Table 2. Afterwards, by looking at the product range of a company that produces upholstery fabrics, folding processes were carried out on the filament yarns so that they could be used as weft yarns especially in upholstery fabrics. The yarns are made of 4 and 6 folds, 700 and 1050 denier yarn finenesses were obtained. Yarn strength test was applied according to TS EN ISO 2062 standard in order to determine the strength of the yarns whose production was completed so that they can be used as weft yarns in upholstery fabrics [23]. Before the test, the filament yarns were conditioned for 24 hours at standard atmospheric conditions of 20°C±2 and 65±2% relative humidity. The Zwick/Roell test device was used to measure the strength values of the yarns. The yarns were subjected to a constant tensile load by being attached to the jaws from the top and bottom, and the strength value at the breaking point was recorded. The distance between the jaws in the device was set as 250 mm and the jaw speed was set as 250 mm/min. As a result of the analysis, the strength values were determined as strength (cN/tex).

3. RESULTS AND DISCUSSION

In the study, MFI test was applied to v-PP and r-PP granules. MFI test determines how much molten plastic extends in a certain time under a certain temperature and load. MFI (Melt flow index) results are shown in Table 3.

Table 3. MFI test results

	v-PP	r-PP	Unit
MFI (230°C, 2.16kg)	22.58	53.32	g/10min

Polymers with high MFI values have low viscosity. This creates a risk of being much more fluid and fiber stability during fiber drawing. However, low fiber stability can cause irregularities and breakage in the fiber structure during drawing [24, 25]. According to the MFI test results, the MFI value of recycled PP gran-

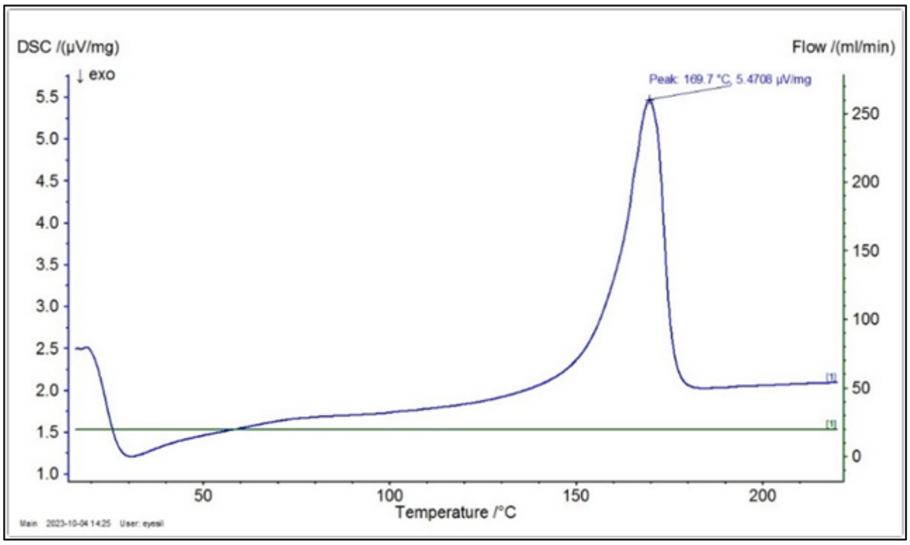

Figure 2. DSC graph of v-PP granules

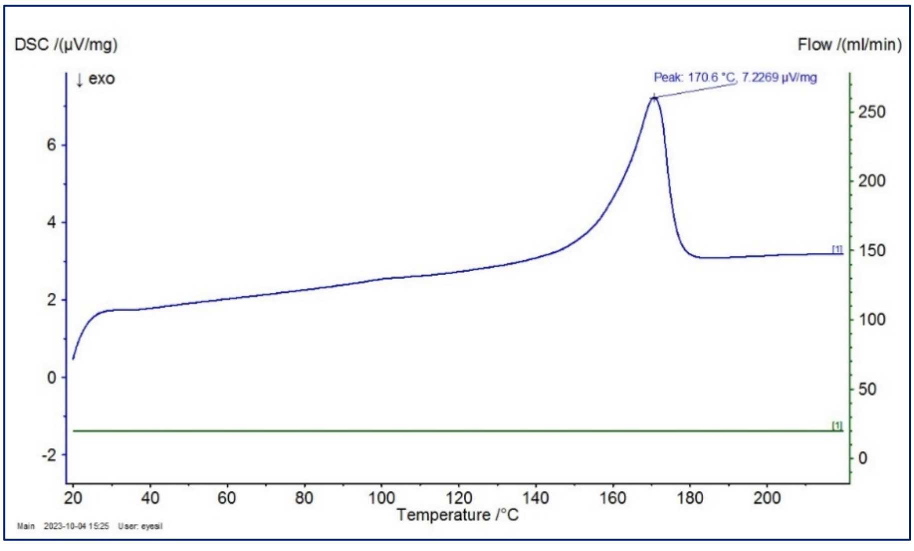

Figure 3: DSC graph of r-PP granules

ules was higher than virgin PP granules. The high MFI value of r-PP granules generally means chain shortening and decrease in molecular weight. During the recycling process, effects such as thermal degradation, oxidation and mechanical fragmentation weaken the chain structure. The MFI value of recycled PP granules was higher than virgin PP granules. While producing yarn containing 30% r-PP, number 4 in Table 2, there were breaks in the yarn during drawing and yarn production could not be carried out successfully. It is thought that the increase in the recycling rate increases the melt flow rate value in the material and therefore causes breaks in the yarn during production [13].

Before proceeding to fiber drawing, DSC (Differential scanning calorimetry) analysis was also performed and evaluated together with MFI results. The main purpose of performing DSC analysis before melt fiber drawing is to determine the thermal properties of the material and optimize the process parameters. Thanks to this analysis, undesirable results (e.g. fiber breakage, irregular drawing, low strength) during production can be prevented in advance. The analysis provides critical information for the efficient and high-quality progress of the process. The determination of the melting temperature, Tm value in the DSC analysis is used to determine the temperature range in which the crystalline phase of polypropylene melts. This information is necessary for the correct determination of the extrusion temperature to be applied during fiber drawing. The determination of the crystallization temperature, Tc value, determines the temperature at which PP begins to crystallize during cooling. This information is important for adjusting the cooling systems and for the proper crystallization of the fiber. The melting enthalpy determines how much crystalline and amorphous phase the granule contains. In other words, the crystallinity ratio is determined. The crystallinity ratio is directly related to the mechanical properties of the fiber, such as strength. DSC analysis can also show whether the granule has been previously subjected to heat treatment. For example, granules obtained from recycling may exhibit different thermal behavior, which affects the fiber drawing quality [26]. The graphs obtained as a result of the DSC analysis applied to polypropylene granules are shown in Figure 2 and 3.

According to the graphs obtained after DSC analysis, the melting temperature of v-PP granules is 169.7 ˚C. The expected melting temperature range for typical isotactic polypropylene is 165–170 °C. This value shows that the polymer has a high crystallinity rate and its purity is intact. At the same time, the presence of a single clear melting peak in the curve indicates that the polymer has a homogeneous crystal structure and is additive-free. This provides a predictable melting behavior and a more stable process during fiber spinning. In short, v-PP granules exhibit high crystallinity, good thermal stability and homogeneous structure according to DSC data. These granules can be evaluated as a suitable and predictable material for fiber spinning. The melting temperature of r-PP granules is 170.6 ˚C. When the peak shapes formed in the graphic curves are examined, a slightly wider curve is seen in the graph in Figure 3. This suggests that the r-PP granule structure is heterogeneous and that there may be other additives in the structure.

After the tests performed on polypropylene granules, filament yarn production with v-PP and r-PP content was carried out by melt spinning. In the study, strength test was applied to the filament yarns planned to be used in the weft yarns of upholstery fabrics. The breaking strength results of the filament yarns produced in the study are shown in the graph in Figure 4.

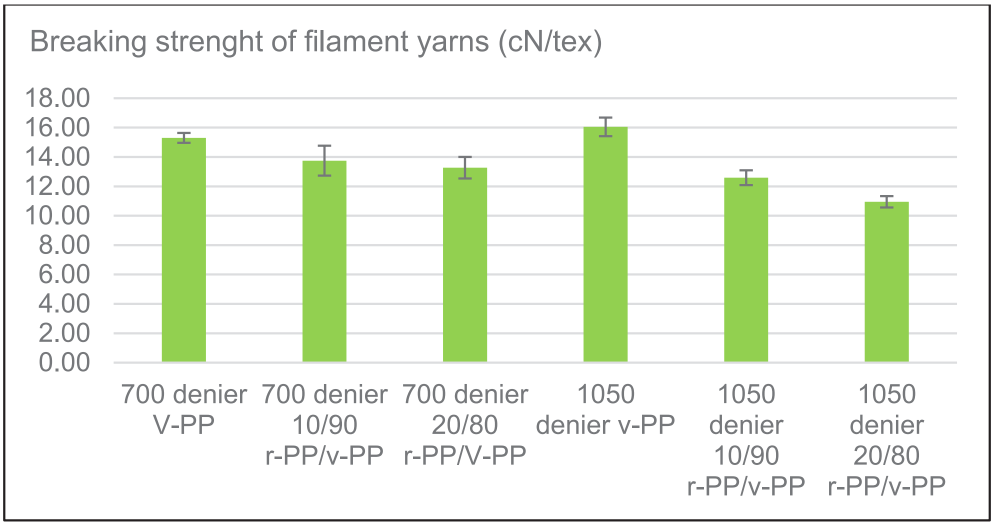

Figure 4: Tensile strength values of yarns

When the strengths of filament yarns are examined, it is seen that the highest yarn strengths are virgin PP yarns that do not use recycled PP. As the rate of recycling contribution increases, a relative decrease in the strength value occurs, and it is thought that this decrease is due to the weakening of the bond between the polymers with the addition of recycling (Sözcü, 2019). However, during the recycling processes applied to waste PP products, contamination by foreign substances to which PP is exposed leads to deterioration in the physical and chemical properties of the fiber. It is thought that this may lead to a decrease in the fiber molecular weight and therefore a decrease in yarn strength [27, 28].

Table 4 shows the two-way ANOVA test results for yarn breaking strength. When the results are examined, it is seen that there is a statistically significant relationship ($p=0.000<0.05$) between the blend ratio and yarn breaking strength and between yarn fineness and yarn breaking strength. When the effects of the independent variables of blend ratio and yarn fineness are examined together, there is a statistically significant relationship ($p=0.000$). In addition, when the 'Partial Eta Squared' section is examined in the analysis, the blend ratio explains 85% of the variance of the dependent variable, while yarn fineness explains 35%. In other words, the r-PP/v-PP blend ratio in the yarn structure is more effective on yarn breaking strength.

It is seen that there is a statistically linear relationship between variables with a Sig. (two-tailed) value below 0.05. The direction and strength of the relationship are interpreted by looking at the Spearman correlation coefficient values. According to the analysis results, there is a strong negative relationship ($0.71<r<0.99$) between the blend ratio and yarn breaking strength. There is a weak negative relationship ($0.01<r<0.29$) between yarn fineness and yarn breaking strength. It was also seen as a result of the statistical analysis that the recycled polypropylene ratio in the yarn structure affects yarn breaking strength the most [29].

4. CONCLUSION

In home textiles, polypropylene yarns are used especially in carpet, rug and upholstery fabric production. Therefore, the aim of the study is to evaluate the recycled polypropylene yarn more in home textile and especially in upholstery fabric structures. The fineness of the yarns produced was determined considering the fineness values that can be used in upholstery fabric production. In the study, filament yarn production was made to be used as weft yarn in upholstery fabric structures. The r-PP filament yarns produced must have sufficient strength in order to contribute to the textile sector again. Yarn strength affects fabric strength. Therefore, with the sufficient strength properties of recycled polypropylene yarns,

Table 4: Two-way ANOVA results for yarn breaking strenght

	Source		df	F	Sig. (p)	Partial Eta Squared
Yarn Breaking Strenght	Main effect	Blend ratio	2	155,789	0.000*	0.852
		Yarn fineness	1	29,513	0.000*	0.353
	Interaction	Blend ratio * Yarn fineness	2	26,936	0.000*	0.499
*Statistically significant (5 % significance level).						

Correlation analysis was conducted to understand the relationship between the variables. The correlation analysis results are shown in Table 5.

Table 5: Correlation analysis results

		Blend ratio	Yarn fineness
	N	30	30
Yarn breaking strength	Correlation Coefficient	-0.792**	-0.259*
	Sig. (2-tailed)	0.000	0.046
	N	60	60
**. Correlation is significant at the 0.01 level (2-tailed).			
*. Correlation is significant at the 0.05 level (2-tailed).			

the necessary studies can be carried out to include these yarns in upholstery fabric structures in the future. This study is of great importance especially in terms of more sustainable and low-cost production in the home textile sector.

The results obtained in the study are summarized below:

- In the study, the production of filament yarns with a blend ratio of 30/70 r-PP/v-PP could not be achieved according to the yarn production plan in Table 2. When the recycled polymer (r-PP) ratio was above 20%, for example 30%, the yield strength during fiber drawing decreased and breaks occurred.
- As a result of the MFI test, the MFI value of recycled PP granules was 53.32 g/10min, and the value of virgin PP granules was 22.58 g/10min. It is thought that the increase in the recycling rate increases the MFI value of the material and therefore may cause breakage in the yarn during production. For these reasons, r-PP granules can be included in production structures if the recycling rate does not exceed 20% and similar production parameters are used. According to the results of variance analysis and correlation analysis, it was seen that the most effective effect on yarn strength was the recycled polypropylene contribution rate in the yarn structure.
- When the strength values of the final yarns are examined in Figure 4, it is seen that there is a relative decrease in the strength value as the rate of recycling contribution increases and, as expected, the highest yarn strengths are in yarns that do not contain recycling contribution.

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