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RESEARCH ARTICLE

SELECTING THE OPTIMUM AMOUNT OF RECYCLED POLYPROPYLENE NONWOVEN WASTE IN SPUNBOND PRODUCTION FOR SUSTAINABILITY

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Abstract

During the Covid-19 pandemic, there was a significant increase in the use of polypropylene-based masks, leading to challenges related to raw material waste and supply limitations. This study aims to identify the optimal ratio of recycled and standard polypropylene fibers to produce a nonwoven spun-bond fabric with the best possible strength and elongation properties. In the rapidly expanding industry, polypropylene (PP)-based nonwoven fabrics (spunbond and meltblown) are increasingly being recycled by converting fabric waste into granules, which are then blended with virgin PP in specific proportions for reuse in production. This research focuses on analyzing the tensile strength and elongation at break of spunbond fabrics. First, fabric wastes from Spunbond-Meltblown processes were converted into granules, and their melt flow index (MFI) values were measured. These granules were then blended with virgin polypropylene fibers in varying proportions, resulting in five different spunbond fabric samples. The mechanical properties of these samples were compared with those of a fabric produced solely from virgin PP. The optimal mixing ratio of recycled to virgin fibers was then determined based on the results. The MFI of the recycled PP1 waste was measured at 38, while the MFI of a 75%-25% Spunbond-Meltblown waste blend (Recycle-PP5) was 104. Spunbond fabrics were produced by blending Recycle-PP1 granules with virgin raw material at ratios ranging from 0% to 20%. It was found that a 10% blend of recycled granules yielded the best results without compromising fabric quality. Higher proportions of recycled granules led to defects in the fabric. For instance, the tensile strength of spunbond fabrics containing 20% Recycle-PP5 granules decreased by approximately 26.9% compared to the fabric produced with 100% virgin PP. This study demonstrates the potential for using recycled granules in spunbond fabric production for specific applications, based on the observed strength properties. A key distinction of this research from existing literature is the identification of the most effective blending ratio of recycled and virgin polypropylene in a conventional production setting.

Keywords

Polypropylene,
Nonwoven,
Spunbond,
Recycling,
Sustainability

Time Scale of Article

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1. INTRODUCTION

Polypropylene is a natural white-colored material obtained by polymerization of propylene monomer produced from "Naphtha", one of the crude oil derivatives. Since derivatives obtained from crude oil at an average rate of 97% are used in its production, its availability and price situation is directly related to world crude oil reserves and prices. Polypropylene is a synthetic fiber, it is one of the thermoplastics that can be reshaped once produced without undergoing and any chemical changes, and is widely used in daily life and industry. Compared to other polymer fibers, it is a 'versatile' fiber whose usage area is increasing day by day. Currently, there are 3 types of polypropylene raw materials used in daily life. Polypropylene homopolymer is produced only from propylene molecules. It is very soft since there is

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no ethylene additive. It is used in the production of materials such as bags. The percentage of ethylene in the polypropylene block copolymer is 3%. It is not very resistant to temperature. It can only be used in the manufacture of plastic pipes that can be used in cold water transmission lines. Polypropylene random copolymer is a raw material whose ethylene percentage is between 3-7%. It can be used where very high temperature and pressure resistance is required. Polypropylene is a highly versatile material used across various industries due to its lightweight, durable, and chemical-resistant properties. In the textile industry, it is utilized for underwear, linings, denim, socks, swimwear, ski wear, and military clothing. For outdoor furniture and upholstery, it features in weather-resistant fabrics like taslan and chenille. In home textiles, it is found in carpets, furniture fabrics, and curtains. The automotive sector uses polypropylene for durable interior and exterior parts, while the construction industry benefits from its use in geotextiles and waterproofing materials. Additionally, it is essential for cable insulation, bottle and pipe manufacturing, and medical applications like syringes and surgical trays. Its adaptability makes it indispensable across these fields.Polypropylene shows very good fatigue resistance. It is low cost and has good impact resistance. It has a low coefficient of friction and provides very good electrical insulation. Chemical resistance is good. It is suitable for all thermoplastic processing processes. The moisture retention rate is less than 0.1%. It has high tensile strength but low abrasion resistance and low resistance to atmospheric effects. Ironing should be applied at lower temperatures than cotton, wool and nylon due to its low melting temperature, difficulty in dyeing after production, low UV resistance and thermal stability [1].

Polypropylene is used more and more in the field of plastic and technical textiles due to its easy availability and advantageous cost compared to other polymers. The increase in the interest in disposable products, especially with the Covid19 pandemic, has increased this consumption even more [2]. The use of disposable products brings with it two difficulties. The first of these is that the demand cannot be met; the second is the increase in the level of waste generated by these products. The importance of recycling is undeniable when it comes to sustainability. Therefore, it is very important to reintroduce the amount of waste generated during production in terms of economic and environmental aspects. The waste of nonwoven fabrics can be used in two ways. The first of these is the reprocessing of nonwoven fabrics produced from thermoplastic polypropylene polymers in the plastics industry. The other is the reprocessing of only spunbond fabrics in the spunbond fabric production machine in the form of feedback. However, the rate in the latter is quite low.

The increasing use of polypropylene and generation of waste during both production and post-consumer phases has emerged as a significant environmental challenge. Recycling these materials back into the production cycle is essential, not only to promote environmental sustainability but also to mitigate the rising costs of raw materials. An area of considerable interest is the optimization of blending ratios between recycled and virgin (standard) granules within production processes, as determining these optimal ratios could support the development of both economically viable and environmentally responsible manufacturing practices.

In response to these challenges, incorporating recycled polypropylene into existing production techniques, such as the spunbond process, presents a viable solution. However, the integration of recycled polypropylene demands a thorough examination of technical obstacles associated with nonwoven fabric manufacturing. By optimizing the blend of recycled and virgin polypropylene, industries can uphold high-quality standards while minimizing environmental impact. The complex nature of the spunbond process, influenced by numerous thermodynamic and aerodynamic factors, underscores the need to determine mixing ratios that preserve both mechanical properties and production efficiency. Thus, investigating these interactions is critical for advancing sustainable and efficient production practices.

Although the spunbond technique is the fastest technique in the production of nonwoven fabrics, the process conditions are quite complex [3,4]. With the help of a thermoplastic polypropylene pump melted in the extruder, thousands of filaments are poured into the mold at the same time using constant pressure and a surface is formed [5,6] After this process, cold air is given to the mold at a certain flow rate. The filaments are oriented by the aerodynamic force between the belt fans. The applied drafting process ensures precise stacking of the filaments [4,7]. The most important parameters at this stage are the air permeability of the belt, the pore density and size of the filament fan screens, the distances of the towers and channels between the die and the belt, the size and number of die holes [8,3,1]. In order for these processes to be carried out properly, thermodynamic, aerodynamic and mechanical processes must be carried out in a controlled manner. For this, the MFI of the polypropylene polymer and the molecular weight distribution of the polymer are very important. In general terms, the more homogeneous the molecular weight, the less decomposition, combustion, or carbonization occurs during thermal processing and the easier the material is to be processed. In addition, the filter or mold does not clog, so the efficiency is high. Since the purest the raw material, the higher the production, the feeding of recycled polypropylene or edge waste to the system reduces the efficiency. Therefore, the amount of feedback that can be provided at the maximum level without reducing the quality varies. Therefore, nonwoven recycling fabric studies are becoming widespread [9-12]. Many studies on polypropylene are related to the plastics industry, but there are also studies using recycled polypropylene in the spunbond production line [13-17].

According to the literature chemical recycling [20-22] (melting and forming granules again) is simple but mainly limited to condensation polymers. Mechanical recycling [21,23] (carding and forming fiber again) is cost-effective, production efficiency is high and technology is well known; however, in this method pre-treatment is needed and this process may deteriorate the product's properties. From the point of this view recycling may not be the real solution for the mill, lanning the production line effectively is better.

In this study, unlike the literature, spunbond and meltblown fabrics were recycled and mixed at different rates to obtain granules again. As a result of the tests applied at the end of the first stage of the study, the most successful mixture was selected and these granules were mixed with pure polymer at different rates to produce spunbond fabrics. The strength and elongation values of the fabrics produced were compared with spunbond fabrics obtained from pure polypropylene.

Research Problem

–To what extent can the different ratios of recycled pp be added to the pure pp?
- What is the optimum recycled granule ratio and production method for the production of nonwoven fabrics?

Objectives

- Selecting the most suitable flow rate to obtain ranules again
-To study the mixing of recycled spunbond and melt blown granules to pure ones and measuring the performance.
- Identify the optimal ratio by measuring the decreasing ratio of strength and elongation both machine and cross directions from pure one.

Research Hypotheses

- The recycled spunbond nonwoven fabrics have the similar strength and elongation values to those of pure nonwoven fabrics (or not?).
- Adding different ratios of recycled granules to pure one causes producing nonwoven fabrics with same quality (or not?).

2. EXPERIMENTAL

Recycling systems typically consist of five primary components: an extruder, filter, mold, coagulation bath, and shaper [10, 14]. The process involves melting and mixing the material in the extruder, purifying and further blending it in the filter, forming the material into filaments using the mold, cooling and stretching the filaments in the coagulation bath, and finally granulating the material with a cutter [17, 18]. Among these stages, filtration and material maturation are considered the most critical for ensuring high-quality output. An additional key factor is the purity of the raw materials used in the process, as it significantly impacts the overall efficiency and quality of the recycled product [11].

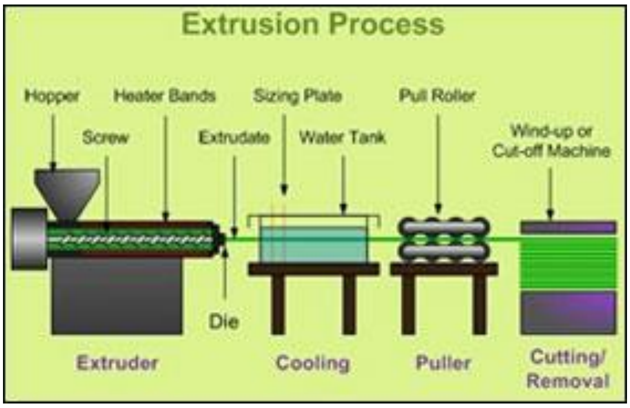

Figure 1. An example of classical extrusion process in a recycle mill [19]

In this study, meltblown fabrics produced from 1200 MFI polypropylene and spunbond fabrics produced from 38 MFI polypropylene were reprocessed into granules, both in their pure forms and as mixed formulations. These granules were then combined with standard polypropylene granules at varying ratios of 3%, 5%, 10%, 15%, and 20%, resulting in the production of five distinct spunbond fabric samples. To check the effect of ratio, a control sample of spunbond fabric made entirely from standard polypropylene was also produced, bringing the total to six different samples. The study utilized spunbond edge wastes derived from 38 MFI polymers and meltblown edge wastes from 1200 MFI polymers. To assess the performance of 24 MFI wastes, an additional sample containing 100% 24 MFI waste was produced. In this paper the standard pp refers to the raw material of the mill and the recycle one is obtained from the waste during production as pre-consumer. It was transformed to granul again and mixed to the original pp in the mill. Other details can not be shared because of the rules of mill. The exact blending ratios used in the study are presented in Table 1.

Table 1. Mixing ratio of spunbond ve meltblown waste

Sample codes	**24 MFI Spunbond ratio**	**38 MFI Spunbond ratio**	**1200 MFI Melt Blown ratio**
Recycle-PP1	%100		
Recycle-PP2		%100	
Recycle-PP3		%95	%5
Recycle-PP4		%90	%10
Recycle-PP5		%85	%15
Recycle-PP6		%80	%20

The purity of the raw material (waste) selected in the recycling process and the filter (mesh) to be used should be compatible with each other. For more fluid meltblown-weighted recycling processes, filters with smaller pore sizes (higher frequency) should be used. In spunbond-weighted processes, filters with larger pores should be used [9,11]. In this study, a 3-layer filter with a porosity of 120*315*18 (mesh) was used and extruder temperatures were adjusted to obtain granules from the mixtures. Production details are given in Table 2.

Table 2. Recycling extruder regional temperatures

Material type	First region °C	Second region °C	Third region °C	Fourth region C	Fifth region°C	Sixth region°C	Seventh region °C
Spunbond	180	185	190	190	195	205	200
Mixture (Spunbond+Meltblown)	195	200	200	205	205	210	210

In terms of purity, nonwoven fabrics with added additives (such as hydrophilic, antistatic, FR, stabilizers, super hydrophobic, UV) can adversely affect the working parameters and even prevent filament formation. For this reason, it is necessary to collect wastes by classification and to use such mixtures in a controlled manner. No additives were used in this study, except for the blue and white dye used in the production of spunbond fabric.

The basic element in adjusting the forces during drafting is to thin the filament as much as possible without breaking. In order to withstand these forces, the molecular chain length of the polymer must be sufficient [18]. For spunbond, this expression can be followed by two values. The first is the difference between 24 and 38 MFI of PP polymer. 38 MFI polymers can operate at lower temperatures and pressures than 24 MFI polymers, and the final product can be obtained with a much softer handle [8]. Another is the distribution of the polymer chain length that makes up the polymer (it doesn't matter if it is 24 or 38 MFI) in the polymer content [18]. The lower (narrower) this distribution, the easier it is to process the polymer and adjust the parameters. More trouble-free productions can be realized. However, if the dispersion is wide, it will respond over a wider range of thermal and aerodynamic forces. However, while this wide range is sufficient to mature some polymers, it will be excessive for some other polymers. As a result, two situations may occur. In the first, burning/carbonization may occur in polymers at high temperatures, while in the other, breaks may occur in filaments that cannot mature before reaching the desired shrinkage amount. When production continues without breaking, filaments that cannot reach sufficient strength may naturally form low-strength fabrics.

It is known that recycled PP granules that can be added to the raw material have a negative effect on the chain lengths in the molecular structure of the polymer. However, since this may vary according to each production machine and the raw material used, how much recycled PP polymer can be used in percentage will be determined in this study. The parameters of the production are presented in Table 3.

Table 3. Production parameters of spunbond fabric

Parameters	Values	Parameters	Values
Extruder Temperature	210-245 °C	Calendar Temperatures	133-134°C
Filter Temperature	238-237 °C	Calendar Printing	85-89 N/mm
Pump Temperature	235-245 °C	Number of Mold Holes	20.000
Pump Speed	19-20 rpm	Die Hole Diameter	30-35 microns
Mold Temperatures	231-245 °C	Raw material PP	24 MFI
Exhaust Fan Speed	750-1050 rpm	Color	White (%60 TiO_2)
Filament Fan Cycle	900-1250 rpm	Belt Fan Cycle	600-780
Filament Fan Air Temperature	10-12°C	Belt Era	270-280 m/min

Recycled PP will be added at rates of 0, 3, 5, 10, 15, and 20% to the pure substance with a MFI of 24. The highest rate that can operate without breakage/problem in the spunbond machine will be determined and its strengths will be examined.

Recycled granules from nonwoven waste will be tested according to the ISO 1133 standard for the determination of melt mass flow rate (MFR) and melt volume flow rate (MVR). In short, the MFI/MFR test is a measure of how much-molten plastic (230°C / 2.16 Kg) flows in 10 minutes (g/10 min) through the standard nozzle under a certain temperature and load. The temperatures and mass applied for each polymer are different and are given in the standards where the polymer is defined. In the PP polymer standard, the temperature is specified as 230 °C and the mass as 2.16 kg. The tests were performed on the Zwick Roell Mflow instrument.

Zwcik Roell brand universal ZwickiLine 0.5 kN model test device was used for the strength of the fabrics produced with recycled polymers. Tests are applied according to ASTM E 8 Standard. 3 tests were aplied as adviced in this standard and the average is used Tests were carried out along both the machine (MD) and fabric width (CD) directions for the study in the test device, in which the breaking strength and elongation at break values were determined. In “ASTM E 8” method, the testing machine shall be operated such that the rate of stress application in the linear elastic region is between 1.15 and 11.5 MPa/s [10 000 and 100 000 psi/min]. The speed of the testing machine shall not be increased in order to maintain a stressing rate when the specimen begins to yield. It is not recommended that the testing machine be operated in closed-loop control using the force signal through yield; however closed-loop control of the force signal can be used in the linear-elastic portion of the test.

3. RESULTS and DISCUSSION

3.1. Determination of MFI of Recycled PP Granules

Granules were obtained from the recycling wastes studied at the temperature values specified in the previous section, and the MFI test results are given in Table 4. MFI tests are applied in accordance with ASTM D 1238-23 standard. Three tests are applied and the average result is used.
MfI

Table 4. MFI test results of recycled granules

Samples	**Density (g/cm^3)**	**MFI (g/10 min)**	**MVR (cm^3/10 min)**
Recycle-PP1	0, 82	23	49,30
Recycle-PP2	0,85	38	59,16
Recycle-PP3	0,84	47	75,89
Recycle-PP4	0,86	67	88,83
Recycle-PP5	0,86	85	130,39
Recycle-PP6	0,86	104	182,70

By using a polymer with a MFI of 1200 MFI, the molecular chains of the polymer exposed to heat treatment (chain length shortens) are broken. During the recycling of meltblown fabrics, i.e. granulation, polymers are again subjected to thermal degradation and the molecular chains of the polymer are broken more. Therefore, 100% meltblown fabrics (Recycle-PP7) could not be recycled and measurements could not be performed. Pictures of other samples are shown in Figure 2.

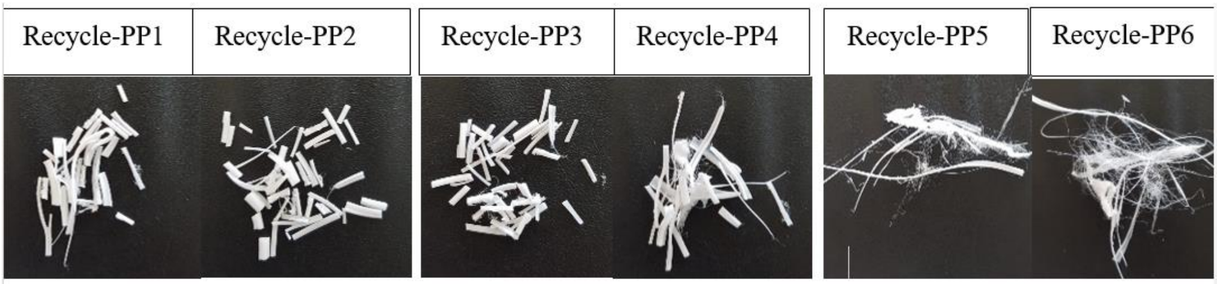

Figure 2. Recycled PP granule samples

As it is known, the density value of PP polymer is 0.91 g/cm^3 [11,18], but it was determined below this value in the measurements. The reason for this difference is that air is trapped inside the granules during granule formation. This undesirable situation is that the frequency of the filter used is not suitable. To solve this, it is recommended to choose a more densely woven lower mesh filter.

As it can be understood from the data, it is seen that the MFI value and naturally the fluidity increase as the amount of meltblown in the mixture content increases. This trend is broken in the Recycle-PP6 sample, because meltblown raw materials with high fluidity are fabrics and become too fluid to form when re-extruded.
Another detected situation is the correlation between the MFI values of the recycled granules produced from spunbond wastes obtained from 24 MFI and 38 MFI polymers. Granules from 24 MFI spunbond wastes are 23 MFI, while granules from 38 MFI spunbond wastes are 38 MFIs. It was observed that the MFI value did not change much with the recycling or extruding of the polymer with a high MFI value. This shows that the higher the MFI value of the PP polymer, the more difficult it is to recycle.

3.2. Determination of Strength Values of Produced Spunbond Fabrics

In this part of the study, spunbond fabric was produced by adding the granules obtained from 24 MFI waste and determined as 38 MFI in the original raw material at the specified rates (0, 3, 5, 10, 15, and 20%). Test results of mass and thickness values are given in Table 5.

Table 5. Mass and thickness values of spunbond fabrics

Sample codes	Granule Ratio (%)	Mass (g/m^2)	Thickness (mm)
Rec-PP1-G0	0%	13,2	0,13
Rec-PP1-G1	3%	12,9	0,15
Rec-PP1-G2	5%	12,8	0,17
Rec-PP1-G3	10%	13,1	0,14
Rec-PP1-G4	15%	12,7	0,15
Rec-PP1-G5	20%	13,3	0,16

The average weight values of the samples were found to be very close to each other with a standard deviation of 0.13%. This result shows how accurate the mold temperature settings, one of the process parameters produced in the spunbond machine, are. It should be noted that the most important observation is the absence of filament breaks that cause drip/melt defects in production. The low standard deviations of the weights of the recycled granule-added samples is another factor that indicates that the process parameters are chosen properly. A similar result can be seen when the mean thickness values and their standard deviation values are examined. The effect of the amount of granules added to the spunbond fabric on the fabric strength is shown in Figure 3.

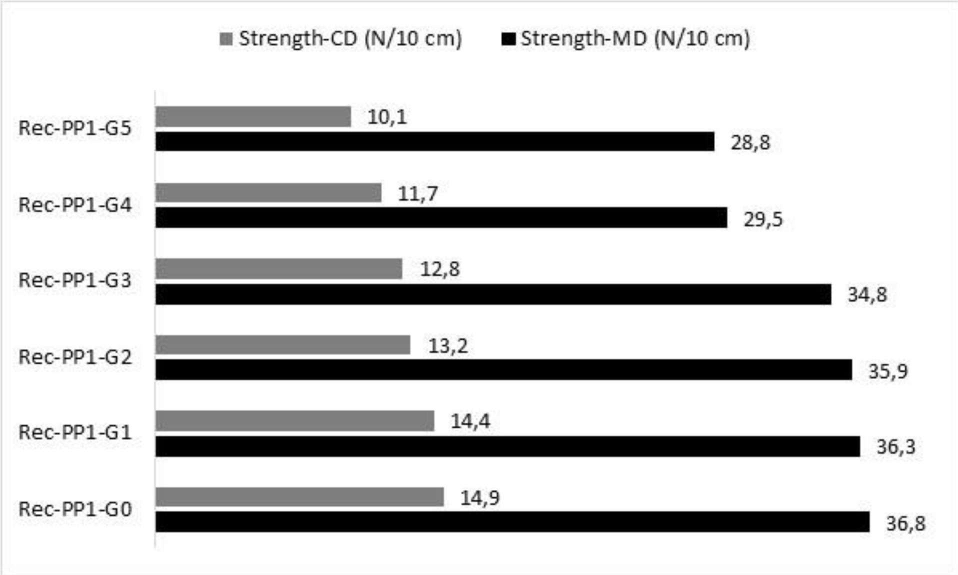

Figure 3. The effect of the increase in the number of granules on the strength of the fabrics

The strength values of spunbond fabrics gain importance according to the place of use of the fabric. Similarly, to give an example for the % elongation value; while the % elongation value is desired to be quite low in lamination processes, % elongation is desired to be quite high in Spunbond fabrics used in elastic nonwoven areas.

Both machine direction (MD) and fabric width (CD) strength values of recycled PP granule-added spunbond fabrics decreased with the increase in the number of granules. While the MD-strength value of spunbond (Rec-PP1-G0) fabric produced without using recycled granules was 36.8 N/10 cm, it was determined as 28.8 N/10 cm in 20% doped spunbond (Rec-PP-G5) fabric. The loss of strength value in the MD direction was determined as 21.7%. A similar situation occurred for the CD-strength value. The strength value loss in the CD direction is 32.2% compared to the MD direction. In this case, it is not recommended to use recycled granules in productions with high strength expectations from 13 g/m^2 spunbond fabrics. For example, it is recommended to use pure raw materials in building-construction textiles and geotextiles. In addition, in the hygiene-medical sector, pure raw materials should be used in accordance with the standards. However, it is understood that up to 10% of recycled PP can be added to fabrics produced for sectors where strength is not important. For example, there is no need for strength in products used as lining in the furniture industry. There is no need for strength in spunbond fabrics used as fruit protectors and fruit mats in fruit crates in the agriculture and greenhouse industry. The graph showing the change in the elongation values of spunbond fabrics with the amount of recycled PP granules is given in Figure 3.

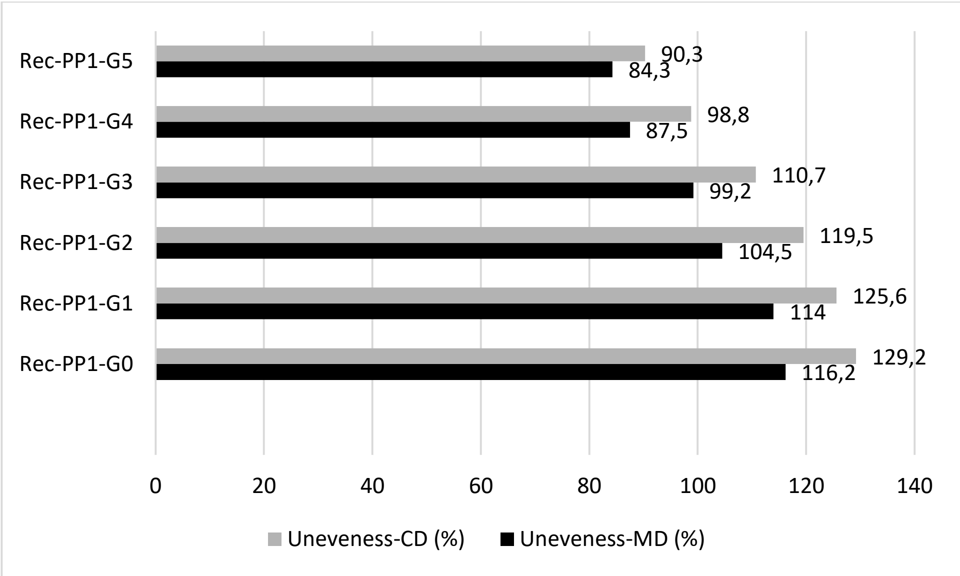

Figure 4. Elongation values of spunbond fabrics according to the number of granules

In Figure 4, the change in %-elongation values of spunbond fabrics obtained by doping recycled PP granules at determined rates was followed. As can be seen from the graph, the MD direction %-elongation value (U-MD) tends to decrease as the amount of added granules increases. The same is true for the U-CD value. A clear trend was not observed in the M-CD graph given in Figure 3. Due to the fact that the filament fan speed and belt suction fan speed values of the process parameters are adjusted in such a way that no breakage occurs in the filament, these settings may have been changed in a way that would affect the filament distribution of the fabric. As a result, low elongation value or keeping it constant at a certain value will facilitate processes such as lamination.

4. CONCLUSION

Polypropylene polymer has seen an extraordinary demand, especially with the Covid-19 pandemic, and manufacturers have not been able to meet this demand. The fact that there are not enough PP manufacturers in our country has created major problems in the supply of raw materials. The thermoplastic structure of PP polymer has enabled this experimental study to be used for the reuse of waste products made of PP polymer as raw materials.

First of all, the first step was to obtain recycled PP granules, which can be obtained by mixing spunbond and meltblown fabrics from nonwoven fabrics in certain proportions, and which will provide trouble-free use in production. As a result of the MFI measurements, the granules obtained from 100% spunbond fabric waste were added to the spunbond fabrics and the production phase was started.

The strength values of the fabrics obtained from recycled PP granules doped between 0 and 20% were investigated. As the doping ratio increased, the strength values in the machine (MD) direction and the fabric width (CD) direction decreased by 21.7%-32.2%, and the elongation value in the machine (MD) direction and fabric width (CD) direction decreased by 27.4%-30,1%. It was determined that there was a decrease of 30 percent. The reason why the amount of recycled PP granules cannot be fed more than 10% is the formation of defects in the fabric. These productions are long-term (8-hour) productions and there was no filament break during the production. However, in the trials of 20% or more (up to 25%), defective areas occurred in the fabric as a result of mold contamination or breaks during the maturation of the filament. For this reason, it is not included in the comparison of strength values. However, this limitation may vary depending on the machine design, the purity of the raw material used, the lower and upper limits needed when setting the process parameters.

With the study, it has been shown that spunbond fabric wastes can be recycled and used at a rate of 10%. In future studies, the usability of recycled granules obtained by increasing the meltblown ratio in the meltblown line should be investigated.

From the perspective of environmental awareness, studies of this kind are highly significant. At the core of this importance lies sustainability, particularly considering that the proportion at which waste generated during production is reintegrated into the system as raw material is not fixed. This ratio can vary depending on the raw materials used by the company, the working conditions, the machinery chosen, and even the working methods of the operators. However, analyzing these values for the company in question and ensuring that the waste produced at the edges is re-granulated or transformed into fibers in opening machines and then recycled into rotor yarn or nonwoven surfaces is highly meaningful. This type of production process is referred to as a closed-loop system. Nevertheless, the data obtained from the company still indicates a waste rate of around 4% in the production line. Conducting LCA analyses on the production line to reduce the level of waste may be more beneficial than converting it back into granules or fibers.

CONFLICT OF INTEREST

The author stated that there are no conflicts of interest regarding the publication of this article.

CRediT AUTHOR STATEMENT

Züleyha DEĞİRMENCİ: Investigation, Writing - original draft, Visualization, Resources Supervision, Conceptualization

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