Title: PLA Blends in Nonwovens

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ABSTRACT

The need to move away from usage of petroleum-based polymers such as polypropylene (PP) in nonwovens so as to move towards a truly sustainable future is in demand with bio-based polymers such as poly (lactic acid) (PLA) leading the change. As a result, the purpose of this study is to continue the investigation and study of PLA and its blends and the structure-property-process relationship of PLA blends in nonwovens. Previous research conducted on the topic concluded that blending PLA, a bio-based polymer, with other bio-based polymers, specifically polybutylene succinate (PBS) and poly-*D*-lactic acid (PDLA) can lead to an increase in the heat deflection temperature of PLLA, eliminate shrinkage in both fully drawn and partially drawn fibers, and increase the crystallinity due to an increase in the crystallization rate. Taking the findings from the previous research conducted, a series of experiments will be conducted in order to first, enhance the thermal bonding of PLLA and the resulting fabric properties using PLA and its blends by conducting a full characterization of spunbond nonwovens and their thermal and mechanical properties. Then, future experiments will investigate charge density and behavior on PLLA/PBS and PLLA/PDLA spunbond fabrics. Furthermore, the first two investigations will lead into the last series of experiments in which the work conducted will be extended to meltblown structures and their characterization.

EXECUTIVE SUMMARY

As a result of the commonly used polymers in textiles and nonwovens such as but not limited to polypropylene (PP), polyethylene (PE), and polyester (PET) not from renewable resources, with an increasing demand to move towards a more sustainable future, the demand and potential for the implementation of bio-based polymers to replace petroleum-based polymers is present and viable. Initiatives such as the United Nations Sustainable Development Goals (SDG) and the Kyoto Protocol has further increased the demand to change. One bio-based polymer from renewable resources that is widely commercially available is poly (lactic acid) or PLA. Despite poly (lactic acid) exhibiting degradability, low energy consumption and CO_2 emissions, and having a comparable, competitive price to that of petroleum-based polymers, there are some drawbacks to PLA as it is brittle, exhibits low elongation strain at break, and has limited thermal stability as it has a low heat deflection temperature (HDT) of around 55-65°C [1]. As a result, while the demand to find sustainable alternatives to the conventional polymers is present, the demand to improve upon the current bio-based polymers so as to serve as an alternative is also present.

Previous research investigating the process-structure-property relationship of poly (lactic acid) (PLA) blends was conducted on melt-spun fibers which determined that certain properties of PLA such as crystallinity, shrinkage, and heat deflection temperature could be improved upon when blended with other bio-based polymers which allowed for not only improvements in certain properties but also did not hinder the potential PLA has in regard to degradability. While it is impossible to improve upon every property of PLA, blending PLA with PDLA, the stereoisomer of PLA as well as blending PLA with poly (butylene succinate) (PBS), another bio-based polymer showed improvements that could be extended towards nonwovens.

In order to extend the previous research conducted, buckets of experiments focused on spunbond nonwovens was designed to further investigate the effect of PLA blends on nonwovens. Currently, benchmark studies with control polypropylene (PP) spunbond nonwovens as well as preliminary benchmark studies with control poly-L-lactic acid (PLLA) spunbond nonwovens were conducted to create foundational characterization of spunbond nonwovens for continued investigation and understanding of nonwovens produced from PLA blends (PLLA/PBS and PLLA/PDLA).

INTRODUCTION

In today's society, there is an increasing demand to rectify the issue of the plastic problem as of the 8.3 billion tons of synthetic polymers and plastics produced, only a mere 9% of the 8.3 billion has been recycled [2]. In addition to the increasing plastics problem accumulating, regulations and calls from both governments, associations, and consumers have increased the need and demand for industries such as the nonwovens industry to move away from petroleum-based polymers predominantly used towards polymers made from renewable and bio-based sources. As a result, investigation of bio-based polymers, such as poly (lactic acid) (PLA), has been the forefront of the change.

OBJECTIVES

As a continuation of a previous research in which the structure-property-process relationship of poly (lactic acid) (PLA) was investigated by blending PLA with other bio-based polymers in order to improve PLA while still keeping the bio-degradable property, the overall goal of this research is to take the findings from the previous research which was conducted on melt-spun fibers and apply it to further investigate PLA blends in nonwovens. Additionally, goals to first, enhance the thermal bonding of PLLA, then enhance the resulting nonwoven properties as well as enhance nucleation and charge density after corona charging, and extend the work conducted on spunbond nonwovens to meltblown charged structures and their characterization are a part of the larger goal. Specific objectives for the current phase are as follows:

- Identify the best blend ratios of PLLA/PBS and PLLA/PDLA
- Investigate the role and rate of crystallization on:
    - Calender bonding
    - Processability
    - Final structure properties
- Characterization of spunbond nonwovens and its impact on crystallinity, shrinkage, heat deflection temperature (HDT), and bonding at different fiber diameters (same throughput, different spinning speeds) and at same fiber diameters (fully drawn with same Jill Ratio)

LITERATURE REVIEW

Poly (lactic acid) (PLA)

Poly (lactic acid) or PLA is a polymer that was first synthesized in 1845 by Théophile-Jules Pelouze and later further developed upon and patented by DuPont and Wallace H. Carothers et al. in 1954 [1]. As a result, poly (lactic acid), hereby referred to as PLA is a polymer that has been in use since then in multiple applications ranging from packaging materials, both flexible and rigid, to apparel to bottles and so on [1]. PLA is a bio-based polymer which is produced via ring-opening polymerization of lactide [1] whose chemical structure can be found in Figure 1. Poly (lactic acid) polymerized from D-lactide is consequently known and identified as poly-D-lactic acid whereas poly (lactic acid) polymerized from L-lactide is known and identified as poly-L-lactic acid. As a result, due to the two different enantiomers and chemical structure, there are two different configurations or types of poly (lactic acid).

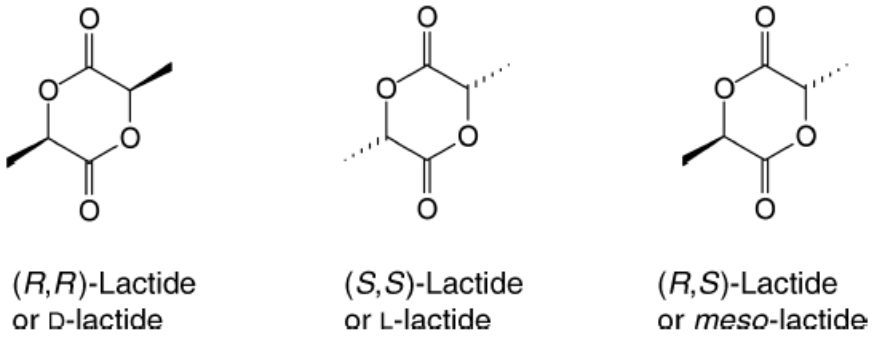


Figure 1. The three diastereomeric structures of lactide (3,6-dimethyl-1,4-dioxane-2,5-dione) showing from left to right, D-lactide, L-lactide, and meso-lactide [1].

The monomer, or basic building block, of poly (lactic acid) (PLA) is lactic acid and is typically derived from renewable resources such as corn, sugarcane, and/or tapioca which are sources of carbohydrates [1]. The chemical structure of the two lactic acid isomers, L-lactic acid and D-lactic acid can be found below in Figure 2. If there is a higher percentage of L-lactic acid forms present in the polymer (i.e., 99% L-lactic acid, <1% D-lactic acid), then the polymer is identified as poly-L-lactic acid (PLLA). On the other hand, if there is higher percentage of D-lactic acid present (i.e., 99% D-lactic acid, <1% L-lactic acid), then the polymer is identified as poly-D-lactic acid (PDLA). The ratio of L-lactic acid and D-lactic acid present in the polymer imparts a significant impact on properties with differences in processing, crystallization, and degradation behavior also being impacted by the overall structure and composition of the polymer chains [1]. Figure 3 shows the chemical structures of poly-L-lactic acid (PLLA) and poly-D-lactic acid (PDLA).



(*S*)-Lactic acid
L-(+)-Lactic acid

(*R*)-Lactic acid
D-(–)-Lactic acid

Figure 2. The two enantiomeric forms of lactic acid, the monomer of poly (lactic acid) from left to right, L-lactic acid and D-lactic acid [1].

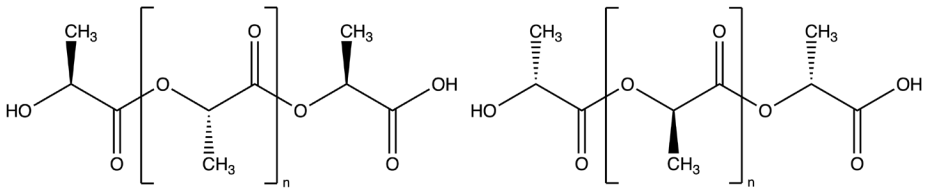


Figure 3. The chemical structure of poly-L-lactic acid (PLLA) (left) and poly-D-lactic (PDLA) (right) with the stereoisomer showcased in the brackets identifying the monomers.

While PLA has been present throughout the years and has been incorporated in a wide variety of applications due to increased processability and production of both poly-L-lactic acid and poly-D-lactic acid as a result of developments in technology, there are still some shortcomings to PLA. While PLA does offer many benefits, especially since it is bio-based, resorbable, and industrially compostable (requires controlled and specific temperatures and pressure) [1], there are some properties of PLA which can be further improved upon if it is to be used in different applications. PLA typically has tensile strength ranging from 44-66 MPa, 4-5.4% elongation at break, and a heat deflection temperature (HDT) of 50-61°C [3]. Despite the differences in properties of PLA compared to other polymers conventionally used in the nonwovens industry, such as polypropylene, the need to further improve upon the properties of PLA is present as does provide other improved properties, especially in regard to being sustainable.

Polybutylene succinate (PBS)

Poly (butylene succinate) or PBS is an aliphatic polyester or long-chain polymer produced from the polycondensation reaction of glycols and aliphatic dicarboxylic acids such as ethylene glycol and/or 1,4-butanediol and succinic acid and/or adipic acid respectively [4]. The chemical structure of poly (butylene succinate) can be found below in Figure 4.

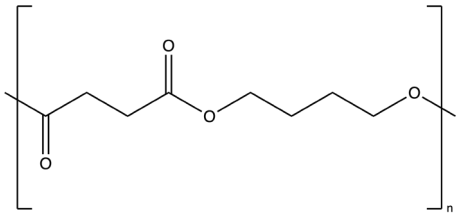


Figure 4. The chemical structure of poly (butylene succinate) (PBS).

Poly (butylene succinate) (PBS) is also a bio-based polymer as its monomers are also derived from renewable resources and therefore can be used with PLA to improve the overall properties without eliminating or hindering one of the main benefits of PLA which is that it is industrially compostable. Poly (butylene succinate) (PBS) exhibits comparable properties to low-density polyethylene (LDPE) with the main difference being that PBS is biodegradable [4]. Poly (butylene succinate) has melting points ranging from 90-120°C, glass transition temperatures within -45 to -10°C, and tensile strength between that of polyethylene (PE) and polypropylene (PP) [4]. Different from poly (lactic acid), poly (butylene succinate) exhibits a wide range of values for different properties based on the type/grade of PBS polymer investigated mainly due to the structure and potentially different processing parameters.

PLA Blends

As mentioned in previous sections, the properties of poly (lactic acid) can be further improved upon and one method of improving the properties of poly (lactic acid) is to blend PLA with other polymers. Previous research determined that blending PLLA with PDLA and PLLA with PBS can lead to improvements in certain properties such as crystallinity, shrinkage, and the heat deflection temperature (HDT) as shown in Figure 5.

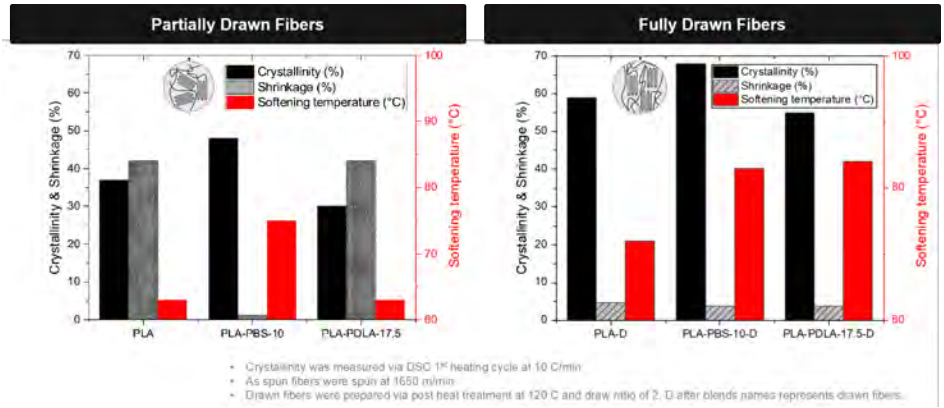


Figure 5. Effect of blending PLA with PBS and PDLA on crystallinity, shrinkage, and heat deflection temperature as adapted from *Ebrahimi H., Pourdeyhimi B. Designing PLA blends to meet sustainability principles and enhance the thermomechanical properties of melt-spun fibers. The Nonwovens Institute. NC State University; 31 July 2021.*

EXPERIMENTAL APPROACH

Initial Design of Experiments

The anticipated project timeline currently consists of three design of experiments with year one focused on full characterization of spunbond fabrics using PLLA/PBS and PLLA/PDLA blends, year two focused on investigation of charge density and behavior of PLLA/PBS and PLLA/PDLA blends for spunbond fabrics, and year three focused on extending the work from years one and two from spunbond nonwovens to meltblown charged structures with potential future years if need be potentially focusing on cost-benefit analysis and/or degradation studies depending on the timeline and research focus.

The design of experiments has undergone multiple iterations and revisions based on multiple feedback. The initial design of experiments consisted of three batches of experiments with experiment 1 focused on the effect of spinning speeds and ratios. Experiment 2 focused on a calender bonding study and Experiment 3 focused on a throughput study. In Experiment 1, the effect of spinning speed and ratios was to be focused on as the spinning speed controls the molecular orientation, crystallinity, and shrinkage. The ratio was focused on as PDLA and PBS can act as nucleating agents which can impact the crystalline structure. As a result, taking the prior research and extending the work and identifying the ideal blend ratio was deemed critical in enhancing the properties of the final nonwoven structure as a result. In Experiment 2, the calender bonding study, the bonding temperature was focused on as the bonding temperature is a parameter that impacts the degree of bonding and fabric properties. Increasing the bonding temperature typically leads to an increase in strength up to a point and then drops due to overbonding and since PLLA has a very narrow bonding window, the calender bonding study was added so as to further investigate it. Lastly, Experiment 3, or the throughput study was focused on in order to further characterize the effects of throughput (in grams/hole per minute, ghm) and spinning speed/draw ratio has on controlling the denier per filament at the same Jill Ratio as the fiber properties should be similar. The Jill Ratio is as follows:

$$Jill\ Ratio = \frac{(1000 * ghm)}{spinning\ speed} \quad \text{(Equation 1)}$$

From the initial design of experiments, the end results from the three batches of experiments of the spunbond trial was to determine the best PLLA/PBS and PLLA/PDLA ratio, lowest basis weight (in g/m^2), ideal calender temperature, and value-proposition in relation to throughput and spinning speeds. In Table 1, the details regarding the three batches of experiments in the initial experimental design is summarized.

Table 1. Initial Design of Experiment for Spunbond Nonwovens

Control – Polypropylene (PP)								
Total Throughput (Kg)	**Total Throughput (Kg/hr.)**	**Denier**	**Fiber Diameter (Microns)**	**GHM**	**Spinning Speed (m/min)**	**Jill Ratio**	**Weight (g/m²)**	**Line Speed (m/min)**
228	220	2.00	17.4	0.67	2995	0.22	20	183
228	220	3.50	23.0	0.67	1711	0.39	20	183
228	220	5.00	27.4	0.67	1198	0.56	20	183
Weight: 20 and 50 g/m² **Calendar Temperatures: 135°C, 140°C, 145°C**								
Experiment 1* **Effect of Spinning Speed and PDLA/PBS Ratio - 2 weights**								
Total Throughput (Kg)	**Total Throughput (Kg/hr.)**	**Denier**	**Fiber Diameter (Microns)**	**GHM**	**Spinning Speed (m/min)**	**Jill Ratio**	**Weight (g/m²)**	**Line Speed (m/min)**
312	300	2.00	15.1	0.91	4083	0.22	20	250
312	300	3.50	20.0	0.91	2333	0.39	20	250
312	300	5.00	23.9	0.91	1633	0.56	20	250
Weight: 20 and 50 g/m² **Ratios: 5.0, 7.5, 10.0, 12.5%** *Red=input; Blue=calculated								
Experiment 2* **Best PDLA/PBS Ratio – Additional Calendar Temperatures (3)**								
Total Throughput (Kg)	**Total Throughput (Kg/hr.)**	**Denier**	**Fiber Diameter (Microns)**	**GHM**	**Spinning Speed (m/min)**	**Jill Ratio**	**Weight (g/m²)**	**Line Speed (m/min)**
312	300	2.00	15.1	0.91	4083	0.22	20	250
312	300	3.50	20.0	0.91	2333	0.39	20	250
312	300	5.00	23.9	0.91	1633	0.56	20	250
Weight: 20 and 50 g/m² **Ratios: 5.0, 7.5, 10.0, 12.5%** **Temperatures: From DSC, corresponding to the amount of crystals that are melted** *Red=input; Blue=calculated								
Experiment 3* **Best PDLA/PBS Ratio – Throughput Study**								
Total Throughput (Kg)	**Total Throughput (Kg/hr.)**	**Denier**	**Fiber Diameter (Microns)**	**GHM**	**Spinning Speed (m/min)**	**Jill Ratio**	**Weight (g/m²)**	**Line speed (m/min)**

162	160	2.00	15.1	0.48	2178	0.22	20	133
234	225	2.00	15.1	0.68	3063	0.22	20	188
312	300	2.00	15.1	0.91	4083	0.22	20	250
415	400	2.00	15.1	1.21	5445	0.22	20	333
*Red=input; Blue=calculated								

Phase I – Control Polypropylene (PP) Spunbond Nonwovens

In Phase I, the control polypropylene (PP) spunbond trial plan was conducted in order to create a benchmark profile to compare the consequent PLA and PLA blend spunbond trials against. The Reicofil R4S single beam spunbond machine was used to produce the spunbond nonwovens. A spinpack of 5510 holes/m was used with a sheath-core design but since it was the control polypropylene, the sheath-core design was not a factor. The polymer used was PP 3155 from ExxonMobil which has a melt flow rate (MFR) of 35 g/10 mins at 230°C/2.16 kg. The melting temperature was 160°C, the processing temperature was 235-260°C, and the degradation temperature was 300°C. Thermal calendering was used as the bonding mechanism so as to investigate the calender bonding temperature with the bond shape being an ellipse. The following five processing variables were studied: basis weight (10, 20, 50 g/m^2), fiber size (17.5, 23, 27.5 microns or 2, 3.5, and 5 denier), calender temperature (135°C, 140°C, and 145°C), throughput (220 kg/m/hr. and 270 kg/m/hr.), and cabin pressure (1000 – 4800 Pa).

Due to limitations of the spinpack, during the actual spunbond trial plan and production of the control polypropylene, changes had to be made from the target or planned trial plan which led to three buckets of experiments within Phase I in which the basis weight, fiber size, and calender bonding temperature was studied. Table 2 shows the details of the samples actually obtained.

Table 2. Details of the Control PP Spunbond Nonwovens from the Basis Weight Study, Fiber Size Study, and Calender Bonding Temperature Study

Basis Weight Study (All Other Variables Held Constant)					
Sample ID	**Basis Weight**	**Fiber Size**	**Calendar Temperature**	**Throughput**	**Cabin Pressure**
1 (1)	10 g/m^2	17.5 microns	135°C	220 kg/m/hr.	3000 Pa
2 (2)	20 g/m^2	17.5 microns	135°C	220 kg/m/hr.	3000 Pa
3 (3)	50 g/m^2	17.5 microns	135°C	220 kg/m/hr.	3000 Pa
Fiber Size Study (Only Calendar Temperature Kept Constant)					

Sample ID	Basis Weight	Fiber Size	Calendar Temperature	Throughput	Cabin Pressure
4 (5A)	20 g/m²	19.8 microns	135°C	270 kg/m/hr.	2500 Pa
5 (6)	50 g/m²	21.6 microns	135°C	220 kg/m/hr.	1000 Pa
Calendar Bonding Temperature Study (All Other Variables Held Constant)					
Sample ID	**Basis Weight**	**Fiber Size**	**Calendar Temperature**	**Throughput**	**Cabin Pressure**
6 (34)	10 g/m²	17.5 microns	135°C	270 kg/m/hr.	4800 Pa
7 (35)	20 g/m²	17.5 microns	135°C	270 kg/m/hr.	4800 Pa
8 (36)	50 g/m²	17.5 microns	135°C	270 kg/m/hr.	4800 Pa
9 (31)	10 g/m²	17.5 microns	140°C	270 kg/m/hr.	4800 Pa
10 (32)	20 g/m²	17.5 microns	140°C	270 kg/m/hr.	4800 Pa
11 (33)	50 g/m²	17.5 microns	140°C	270 kg/m/hr.	4800 Pa
12 (28)	10 g/m²	17.5 microns	145°C	270 kg/m/hr.	4800 Pa
13 (29)	20 g/m²	17.5 microns	145°C	270 kg/m/hr.	4800 Pa
14 (30)	50 g/m²	17.5 microns	145°C	270 kg/m/hr.	4800 Pa

In order to create the benchmark profile, the following tests were conducted on the control polypropylene spunbond nonwovens obtained from the spunbond trial: tensile testing, fiber size (SEM and Keyence microscopy), air permeability, bursting strength (TruBurst), thickness, orientation distribution function (ODF), and basis weight uniformity.

Phase II – Control Polypropylene (PP) and Control PLA Spunbond Nonwovens

In order to create the benchmark profile, the following tests were conducted on the control polypropylene spunbond nonwovens obtained from the spunbond trial: tensile testing, fiber size (SEM and Keyence microscopy), air permeability, bursting strength (TruBurst), thickness, orientation distribution function (ODF), and basis weight uniformity.

Phase II – Control Polypropylene (PP) and Control PLA Spunbond Nonwovens

Due to challenges in Phase I during the fiber size study, as the higher fiber sizes of 23 and 23.5 microns (3.5 and 5 denier respectively) were not able to be produced as the 5510 holes/meter spinpack was a limitation, in Phase II, continuation of Phase I in producing the higher fiber size diameter control polypropylene (PP) spunbond nonwovens was conducted to complete the control polypropylene benchmark profile. In order to produce higher fiber sizes, the spinpack was changed from the initial 5510 holes/meter used in Phase I to a 3507 holes/meter spinpack in Phase II. Due to the change in the spinpack, the higher fiber size diameters were able to be obtained to create an overall comprehensive sample profile to compare the future PLA blend spunbond nonwovens against. Table 3 shows the sample details of the control polypropylene samples produced as a continuation of Phase I.

Table 3. Details of Continued Phase I – Control PP Samples

Phase I – Control PP Spunbond Nonwovens Basis Weight and Fiber Size Study (All Other Variables Held Constant)					
Sample ID	**Basis Weight**	**Fiber Size**	**Calendar Temperature**	**Throughput**	**Cabin Pressure**
20220404_01	50 g/m^2	23.6 microns	145°C	270 kg/hr.	4000 Pa
20220404_02	20 g/m^2	23.0 microns	145°C	270 kg/hr.	4000 Pa
20220404_03	10 g/m^2	22.9 microns	145°C	270 kg/hr.	4000 Pa
20220404_05	20 g/m^2	26.4 microns	145°C	270 kg/hr.	2500 Pa
20220404_06	50 g/m^2	26.0 microns	145°C	270 kg/hr.	2500 Pa

Additionally in Phase II, the spunbond trial for the 100% PLA 6100D from NatureWorks, LLC was detailed and planned out, with a focus on determining the limits of basis weight and fiber size through a calender bonding study, similar to the spunbond trial plan detailed and conducted in Phase I. The main objective of the control PLA spunbond trial plan of Phase II was to determine the limits in regard to the aforementioned variables of basis weight, fiber size, calender bonding temperature, throughput, and cabin pressure from Phase I.

However, due to engineering challenges, the control PLA spunbond trial plan had to be adjusted. As a result, only four test samples were obtained during the spunbond trial. Table 4 details the specifics of the control PLA test samples.

Table 4. Details of Test Samples obtained from Phase II – Control PLA

Phase II – PLA 6100D Spunbond Nonwovens Change in Cabin Pressure (All Other Variables Held Constant; Variation between Samples)					
Sample ID	**Basis Weight**	**Fiber Size**	**Calendar Temperature**	**Throughput**	**Cabin Pressure**
20220405_1	51 g/m^2	18.5 microns	140°C	270 kg/hr.	7500 Pa
20220405_2	58 g/m^2	17.3 microns	140°C	270 kg/hr.	7500-9000 Pa
20220405_4	54 g/m^2	18.2 microns	135 – 140°C	270 kg/hr.	9000 Pa
20220405_5	55 g/m^2	17.3 microns	140°C	270 kg/hr.	9000 Pa
*variation in basis weight, fiber size, and calender temperature due to fluctuations during sample production in order to get target parameters					

The main challenge of the control PLA in Phase II was static charge build-up occurring in between the compaction roll and the calender roll where thermal bonding occurs, well after proper extrusion of the polymer through the spinneret and quench chamber. A schematic of the spunbond process can be found in Figure 6 for reference. Although Figure 6 does not explicitly show the compaction roller, in the actual line, it can be found right after the laydown and right before the bonding area as shown in Figure 6. As a result of the excessive static charge build-up occurring in the line, the web wrapped around the top calender roll which should not occur as the web should ideally go through the two calender rolls and undergo bonding. Due to excessive static charge build-up, only four test samples of the control PLA spunbond nonwovens were obtained during the trial plan which allowed for a preliminary investigation of PLA 6100D.

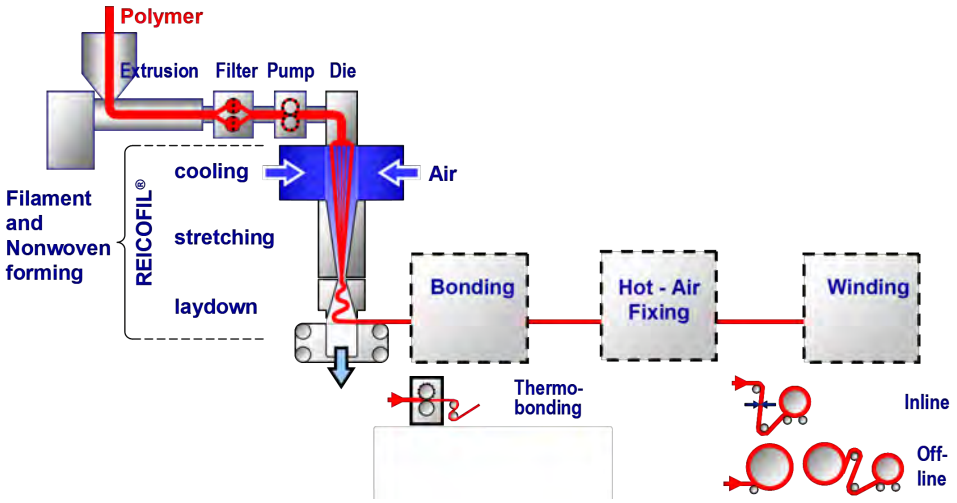


Figure 6. Schematic of a Spunbond Process Line adapted from Hans Georg Geus, Nonwovens Technology, Products & Market Potential, Oct 2005, Indian Institute of Technology, Delhi.

Upon investigation of patents regarding production and processing of 100% PLA nonwovens, three potential solutions exist in order to remove the static charge build-up. According to US Patent 20200165761A1, one potential solution is to increase the humidity by injecting steam so as to provide a fine mist of moisture to remove and dissipate the static charge that gets built up but the eventual accumulation of moisture during creation of the nonwovens may lead to destruction of equipment parts as well as have an impact on nonwovens used in hygiene and medical applications as the addition of moisture may lead to growth of microorganisms which is not desirable for such applications [5]. A second solution to remove the static charge build-up is to use a conductive static bar which will require contact between the web and conductive substrate to ground the web and remove the charge; however, much like the first solution, issues with this solution is present as use of such a solution may also lead to equipment damage as well as operator harm which are also two undesirable effects [5]. A third potential solution is the implementation of ionization sources near the spin beam and winder to dissipate the static charge build-up through the use of a stream of ions that could include positive ions, negative ions, a combination of positive and negative ions to neutralize the static charge build-up [5]. And lastly, it has been suggested that the incorporation of an idle static charge removing roller within the spunbond process line may lead to the removal of static charge build-up [5]. Taking findings from literature as well as learning of the different engineering challenges currently present, the next steps will be determined based upon further feedback and discussions.

SUMMARY & CONCLUSIONS

Due to the increasing demand for industries, including the nonwovens industry to move towards a truly sustainable future, the viability and interest in bio-based polymers has increased allowing for further investigation and studies of such relevant bio-based polymers to be conducted in order to move away from utilizing non-renewable, petroleum-based polymers. While full integration of bio-based polymers and total replacement of the currently employed polymers such as polypropylene, polyethylene, polyester, and polyamide would be ideal, the need to improve upon the properties of currently, commercially available bio-based polymers are also present. Initial studies conducted have investigated the use of poly (lactic acid), a widely available bio-based polymer with many promising properties as the polymer to use in moving forward towards a more sustainable future. As a result, preliminary studies have shown that blending PLA can improve upon its properties so as to serve as an alternative to petroleum-based polymers. Specifically, previous research has shown that blending PLA with PBS and PDLA has led to improvements in crystallinity, shrinkage, and heat deflection temperature without the need to add additional steps.

As a result, in the present research, the investigation of structure-property-process relationships of PLA blends in nonwovens are being investigated so as to act upon the improvements and extend the work conducted on melt-spun fibers towards nonwovens. The creation of the control polypropylene spunbond nonwoven benchmark profile investigating the different processing parameters and its effects on different properties provided beneficial results and a base framework for the future studies. Additionally, the preliminary investigation of the control PLA spunbond nonwovens in which 100% poly-L-lactic acid (PLA 6100 from NatureWorks LLC) was utilized also provided another set of benchmark data to utilize as the research moves forward with the PLA blend studies. While further work needs to be conducted regarding data analysis, overcoming engineering challenges, and more in-depth investigation of the PLA blends, the initial foundational work was conducted to guide the research forward.

FUTURE WORK

The initial subject and time planning for this project was as follows:

1.	Literature Review	Aug. 2021 – Apr. 2022
2.	Benchmark Control PP Spunbond Trial	Jan. 2022
3.	Characterization of Control PP Spunbond	Jan. 2022 – Apr. 2022
4.	Benchmark Control PLA Spunbond Trial	Mar. 2022
5.	Characterization of Control PLA Spunbond	Apr. 2022

6. Parallel Control PLA Spunbond & Characterization — May-Jun. 2022
7. PLA Blend Spunbond Trial — Jul. 2022
8. Characterization of PLA Blend Spunbond — Jul. – Aug. 2022
9. Full investigation of charge density/behavior — Aug. 2022 – Apr. 2023
10. Extend work on spunbonds to meltblowns — May 2023 – Dec. 2023
11. Potential future studies — Jan. 2024 – May 2024

In line with the schedule, the literature review of the material and topic at hand is continuing to be conducted. Additionally, the benchmark profile for the control polypropylene (PP) spunbond nonwovens was conducted and is being finalized. Furthermore, the control PLA spunbond trial plan was initiated. As a result of the results, challenges, and discussions, a parallel control PLA spunbond trial plan involving Ingeo™ PLA 6752D and Ingeo™ PLA 6100D sheath-core will be investigated in order to create a comprehensive benchmark profile for the future PLA blend studies.

Once the data analysis for the control PLA spunbond nonwovens is conducted and the processing parameters to move forward with are established, the PLA blend (PLLA/PBS and PLLA/PDLA) studies will be conducted at 12.5%, 10%, and 7.5% blend ratios as determined from the previous research project. Full investigation and characterization of the spunbond nonwovens will be conducted before moving onto investigation of charge and extending the work from spunbond nonwovens to meltblown nonwovens. Furthermore, studies investigating degradation may potentially be conducted in order to create a comprehensive overview of PLA blends in nonwovens.

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