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Use of Thermal Black in PLA films for industrial applications

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2,151
SCIENTISTS, ENGINEERS, TECHNICIANS, AND OTHER SPECIALISTS

179
BUILDINGS MANAGED on 22 SITES

$1.1B
ANNUAL EXPENDITURE
including an IRAP contribution budget of $293M for SMEs

1,577
R&D COLLABORATIONS AND HELPED 8,000 SMEs

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● RESEARCH FACILITIES AND NRC IRAP OFFICES

NRC is the Government of Canada's largest R&D organization with over 100 years of experience

Sustainable polymer products at NRC

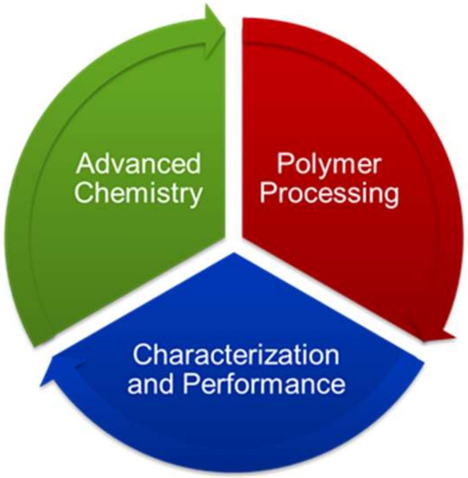
Mission and Research areas

Support to NRC's Advanced Manufacturing Program

Automotive & Surface Transportation
Research Center

Support to Government Policies

Zero Plastic Waste Strategy and Circular Economy (2018)



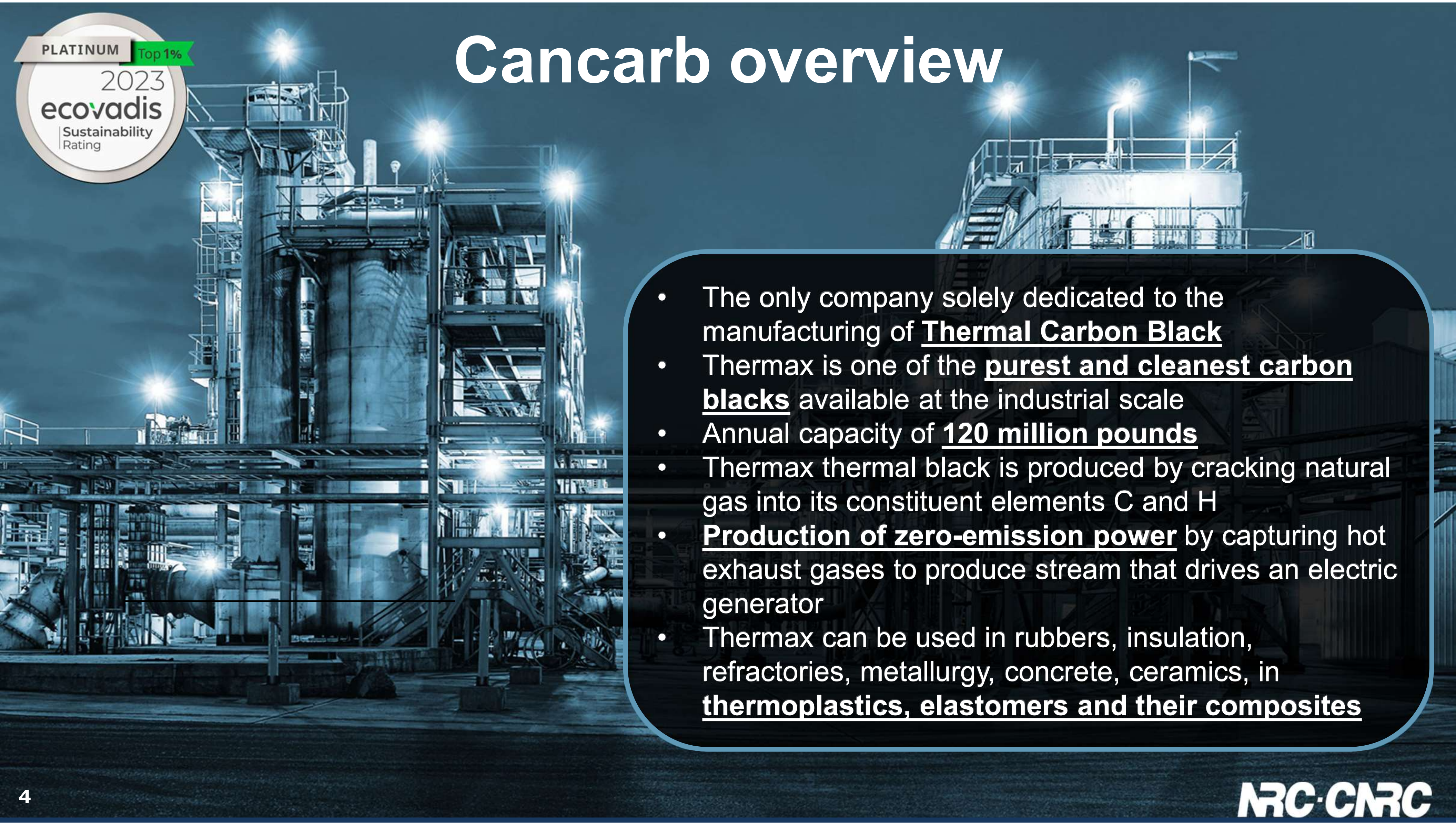
Advanced Chemistry

Polymer Processing

Characterization and Performance

Eco-Responsible Materials & Advanced Processes

Bioplastics & Biocomposites
Lightweight Polymers & Composites
Polymer Recycling
Biorefining



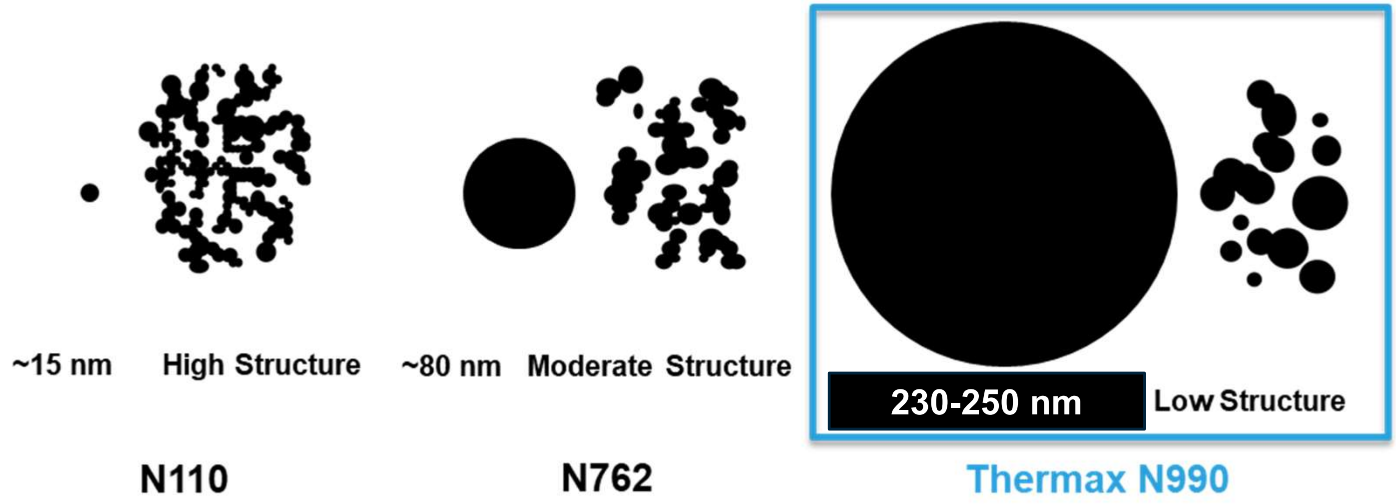
PLATINUM Top 1%
2023
ecovadis
Sustainability
Rating

Cancarb overview

- The only company solely dedicated to the manufacturing of **Thermal Carbon Black**
- Thermax is one of the **purest and cleanest carbon blacks** available at the industrial scale
- Annual capacity of **120 million pounds**
- Thermax thermal black is produced by cracking natural gas into its constituent elements C and H
- **Production of zero-emission power** by capturing hot exhaust gases to produce stream that drives an electric generator
- Thermax can be used in rubbers, insulation, refractories, metallurgy, concrete, ceramics, in **thermoplastics, elastomers and their composites**

Thermal Black vs. Furnace Black

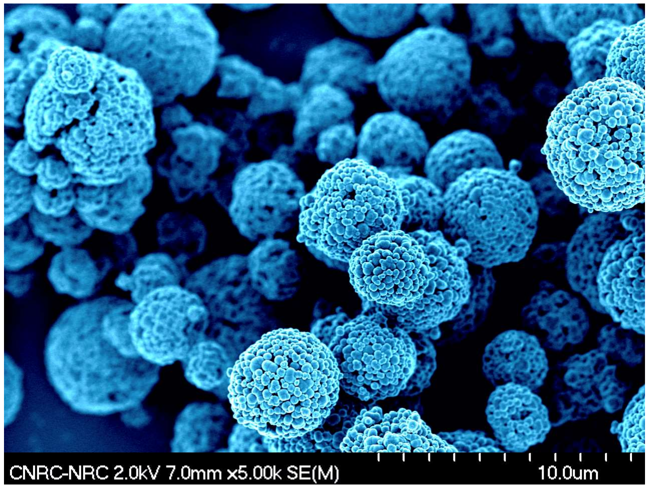
Particle Size Diameter and Structure



- ➢ Carbon black can be defined as very fine particle aggregates of carbon, possessing a paracrystalline molecular structure, while Thermal Black has an amorphous structure
- ➢ The main distinction between Thermal Black and Furnace black are particle size and structure
- ➢ Thermal Black, due to its higher particle size and lower structure, compared to even the most coarse furnace black, can be translated into excellent properties of the thermoplastic composites

Outline

- **State-of-the-art on PLA films**
- **Extrusion of compounds and cast-film extrusion**
- **Mechanical/Thermal/Morphology Characterizations**
  - **Cast films**
  - **Biaxially stretched films**
  - **Blown films**
- **Complementary characterization**
  - **Biodegradability**
  - **Barrier properties**
  - **Optical properties**
- **Conclusions**



Thermal Black Thermax® N990 from spray drying

State-of-the-art on PLA films

Results from manufacturers of PLA - grades recommended for film applications

TS at break MD/TD (MPa)	Elongation at break MD/TD (%)	Film thickness (µm)	Grade/Manufacturer	Applications
37.6 / NA	290 / NA	30	EcoHumer BFX303, WooSung Chemical Co., Ltd.	Blown films for different applications
29 / 21	280 / 400	20	Bio-Flex® F 1138, FKuR Kunststoff GmbH	T-shirt bags, waste bags
103 / 145	180 /100	25	4032D, NatureWorks® LLC	Biaxially oriented film, use temperatures up to 150°C
47 / 40	440 / 350	50	Ecovio® F2224, Copolyester, BASF Corporation	Blown films for different applications

Results from manufacturers of PLA films - values from TDS

TS at break MD/TD (MPa)	Elongation at break MD/TD (%)	Film thickness (µm)	Grade/Manufacturer	Applications
28 / 26	400 / 650	25	Ginegar Plastic Products Ltd.	Commercialized Mulch films
20 / 16	480 / 580	30	Bio-Flex® FX 1824, FKuR Kunststoff GmbH	Compostable bags made by film blowing

Results from scientific literature published on PLA films

TS at break MD/TD (MPa)	Elongation at break MD/TD (%)	Film thickness (µm)	Reference	Recommended Applications
60 MPa - 1.5 mm cast 100 MPa - 0.7 mm BO	20 % - 1.5 mm cast 120% - 0.7 mm BO film	1.5 mm - cast film 0.7 mm - bi-ax film	ACS Sustainable Chem. Eng. 2021, 9, 6296−6304	**PLA 4032D / silica particles composite** Superhydrophobic biodegradable PLA films, excellent self-cleaning and mechanical properties, Combining casting-thermal stretching and surface treatment.
50 - 60 MPa for films of 500-550 µm 90 - 120 MPa for films of 170 - 190 µm	5% for films of 500-550 µm 35 - 50% for films of 170 - 190 µm	500 to 550 µm 170 to 190 µm	Int J Biol Macromol, 2021 Jun 30;181:521-527.	**PLA 4032D with hydroxyl-terminated polybutadiene (HTPB) films** Extruded film, great mechanical O2 barrier properties.

Compounding and cast-film extrusion

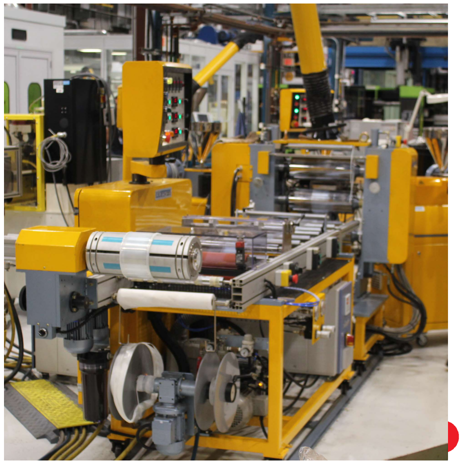
Extrusion:
PLA 4032D from NatureWorks® - grade for films for industrial, shopping and trash bags.
Thermal Black (TB) Thermax ® N990 - from Cancarb Ltd.

Matrix	TB N990 content wt.%						CB N762 content wt.%
PLA	0	3	10	20	15	40	20

All compounds were used further in cast-film extrusion, biaxial stretching, and film blown processes.

Compounding

Extrusion casting



Film casting:
Extrusion of cast films with a thickness of ca. 100 μm from each formulation and from pristine PLA as well.

The cast film obtained from PLA containing 40 wt.% TB proved to be very brittle and was discarded. A dilution was done down to PLA / 15 wt.% TB and extruded to obtain again cast films.

Characterization of PLA - TB cast films

Mechanical testing:

- Tensile properties according to ASTM D882-18: *Standard Test Method for Tensile Properties of Thin Plastic Sheeting;* Parameters used: 5 kN cell, 100 mm grips distance, 10 mm/min speed
- All samples were conditioned at 23 ^{o}C, 50% RH and 40 hours and tested in Machine Direction (MD)

- For TB contents from 3 up to 20 wt.%, TS presented values of 41 - 46 MPa and the Elongation was around 2.5%, therefore those values are similar to pure PLA.
- This performance of cast films can fit in applications having UV blocking properties

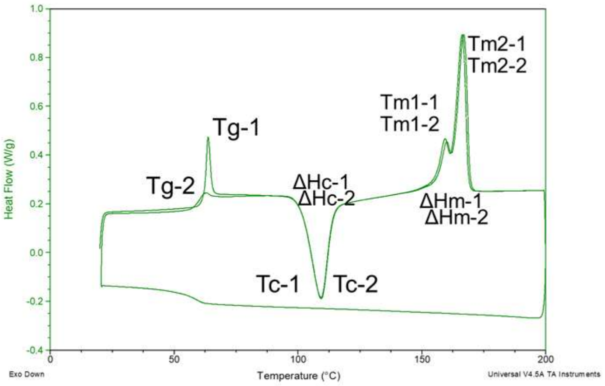
	TB content wt.%	**Thickness µm**	SD mm	**Tensile Modulus MPa**	SD TM MPa	**Tensile Strength MPa**	SD TS MPa	**Elongation %**	SD %
PLA-0	0	118	0.01	2385.27	82.10	49.17	1.02	2.62	0.13
PLA-1	3	121	0.01	2015.99	151.22	44.75	1.62	2.99	0.13
PLA-2	10	125	0.01	2593.41	156.13	46.23	3.63	2.61	0.33
PLA-5	15	138	0.01	2722.38	82.88	44.80	2.69	2.64	0.30
PLA-3a	20	145	0.01	2878.00	84.56	40.59	4.05	2.09	0.23
PLA-3b	20	139	0.00	2759.42	71.79	48.15	1.77	2.52	0.18
PLA-4	40	-	-	-	-	-	-	-	-

Characterization of PLA - TB cast films

Differential Scanning Calorimetry - DSC

The DSC analysis was done between 20 ^{o}C and 200 ^{o}C, at a rate of 10 ^{o}C/min

TB Content wt.%	Heat 1 Behavior after casting						Heat 2 Innate behavior					
	Tg-1 ^{o}C	ΔHc-1 J/g	Tc-1 ^{o}C	ΔHm-1 J/g	Tm1-1 ^{o}C	Tm2-1 ^{o}C	Tg-2 ^{o}C	ΔHc-2 J/g	Tc-2 ^{o}C	ΔHm-2 J/g	Tm1-2 ^{o}C	Tm2-2 J/g
0	63.5	33.7	123.8	36.9	164.5	-	61.5	35.7	124.0	36.7	160.3	-
3	63.7	34.2	113.6	37.1	162.6	168.8	61.3	33.2	114.3	38.5	163.0	169.1
10	63.9	31.9	113.2	33.0	162.4	168.9	61.7	32.3	113.2	36.1	162.3	168.7
15*	57.7	27.1	105.1	33.3	151.6	167.5	61.3	26.8	105.1	36.7	152.0	167.5
20	63.3	26.2	111.6	32.1	161.7	168.5	61.3	26.9	111.2	32.7	161.3	168.2
20 (CB)	63.6	25.2	109.0	25.2	162.0	168.3	61.9	25.0	109.5	29.5	161.9	168.3
40	63.1	20.5	109.1	27.7	159.8	166.9	60.8	21.4	109.2	26.6	159.2	166.3



Tg-1 and Tg-2, remained unchanged for all formulations.
Tm, for both heating cycles, remained also unchanged with increasing TB content.
Tc, for both cycles, decreased with increasing TB content: TB particles play the role of nucleating agent for crystallization

*15% TB was obtained by dilution 40% TB. Therefore the PLA was extruded 2 times and a possible slight degradation took place (normal for PLA)

Characterization of PLA - TB cast films

Differential Scanning Calorimetry - DSC

Theoretical melting enthalpy of a 100% crystalline PLA is $\Delta H_{100\% \, PLA} = 93$ J/g.

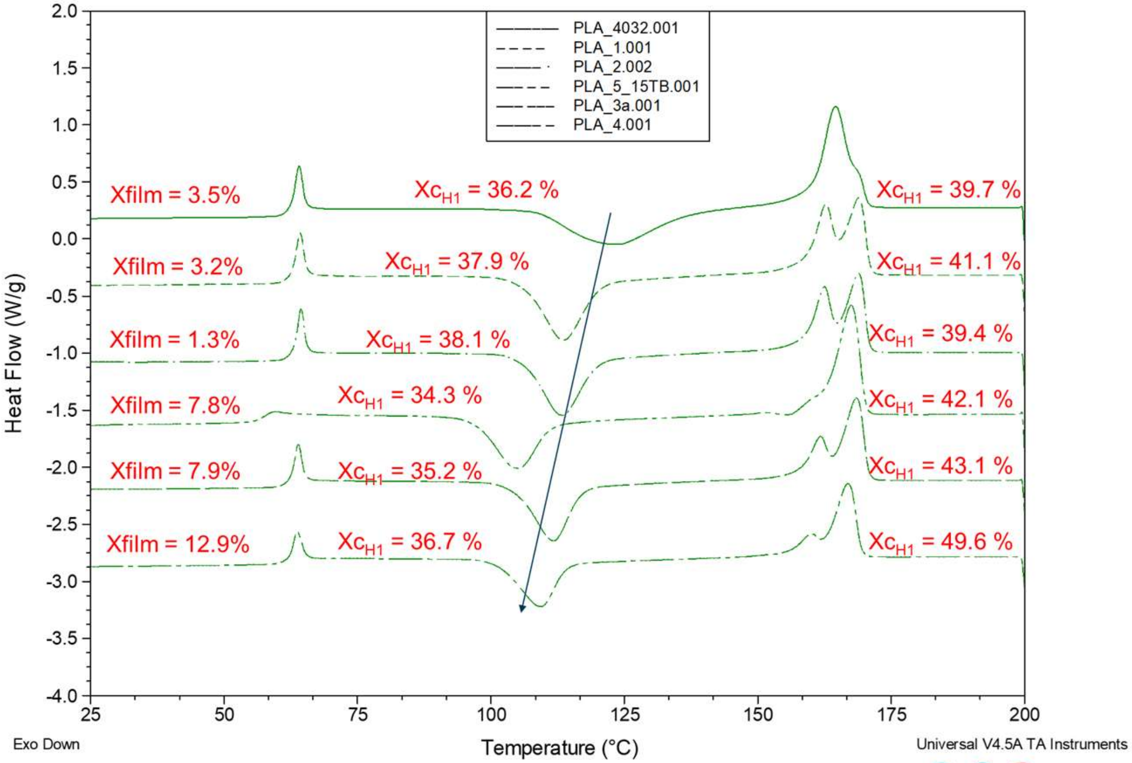
The crystallinity was calculated as follows:
$X \% = \Delta H / (1 - TB\%) \Delta H_{100\% \, PLA}$
Where TB% is: 0, 0.03, 0.1, 0.15, 0.2 and 0.4 corresponding at 0, 3, 10, 15, 20 and 40% TB in PLA

The PLA and PLA/TB crystallize during the heating, therefore the materials were not fully crystallized during the film casting process. The calculated crystallization % is presented in red in the figure.

Increasing TB%, from 3 to 40 wt.%, increased slightly the crystallinity of cast films from 3.5 up to 12.9%. Therefore, TB played a role of nucleating agent.

Very similar values were obtained for the cycle Heat 2

Heat 1: cycles comparison (Heat 2 cycles presented very similar trend)



Characterization of PLA - TB cast films

Differential Scanning Calorimetry - DSC

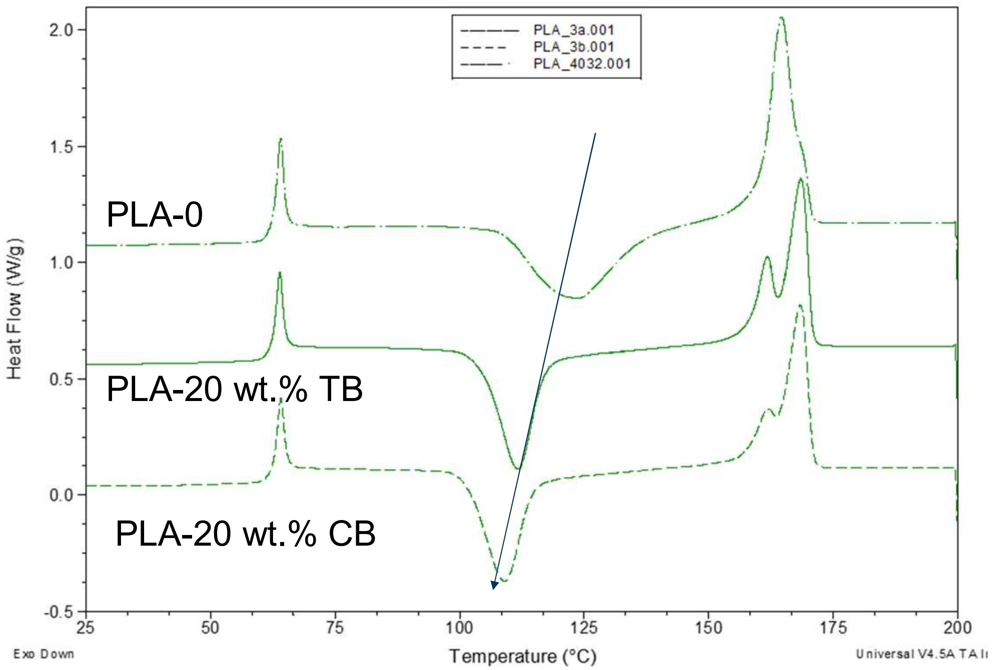
	Thermal Black Content wt.%/100	Heat 1 Behavior after casting							
		Tg-1 ºC	ΔHc-1 J/g	Xc H1 %	Tc-1 ºC	ΔHm-1 J/g	Xm H1 %	Tm1-1 ºC	Tm2-1 ºC
PLA-0	0	63.5	33.7	36.2	123.8	36.9	39.7	164.5	-
PLA-3a TB	0.2	63.3	26.2	35.2	111.6	32.1	43.1	161.7	168.5
PLA-3b CB	0.2	63.6	25.2	33.9	109	25.2	33.9	162.0	168.3

PLA / 20 wt.% TB and PLA / 20 wt.% CB presented very similar thermal behaviors, i.e. similar Tg and Tm.

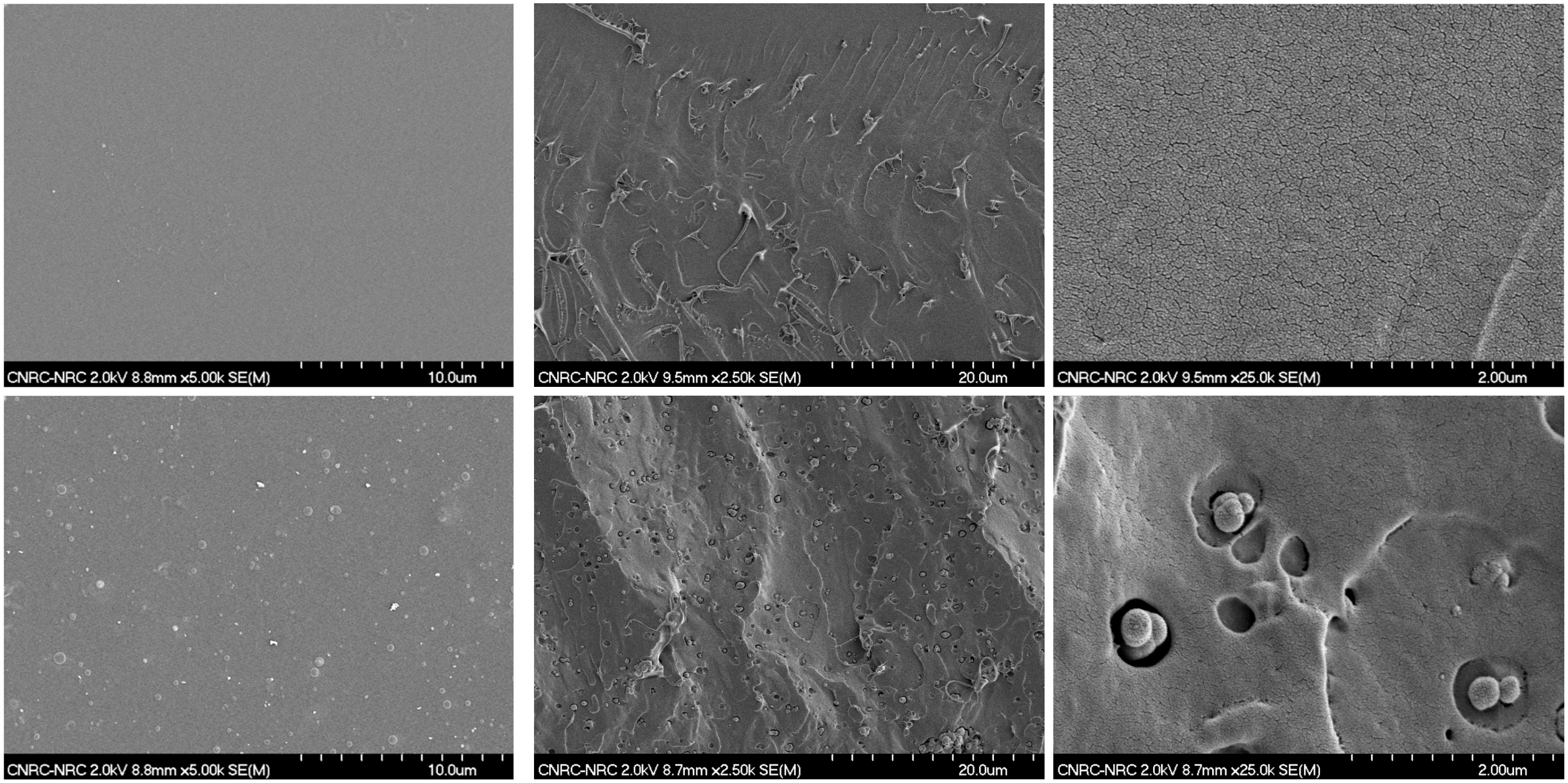
Exception for the crystallization behaviors: Tc and crystallinity content were lower for PLA-CB composite.

Reason: CB particles, being much smaller than TB particles, around 50 nm compared at 230-250 nm, at 20 wt.% CB there are a higher number of particles compared at 20 wt.% TB.

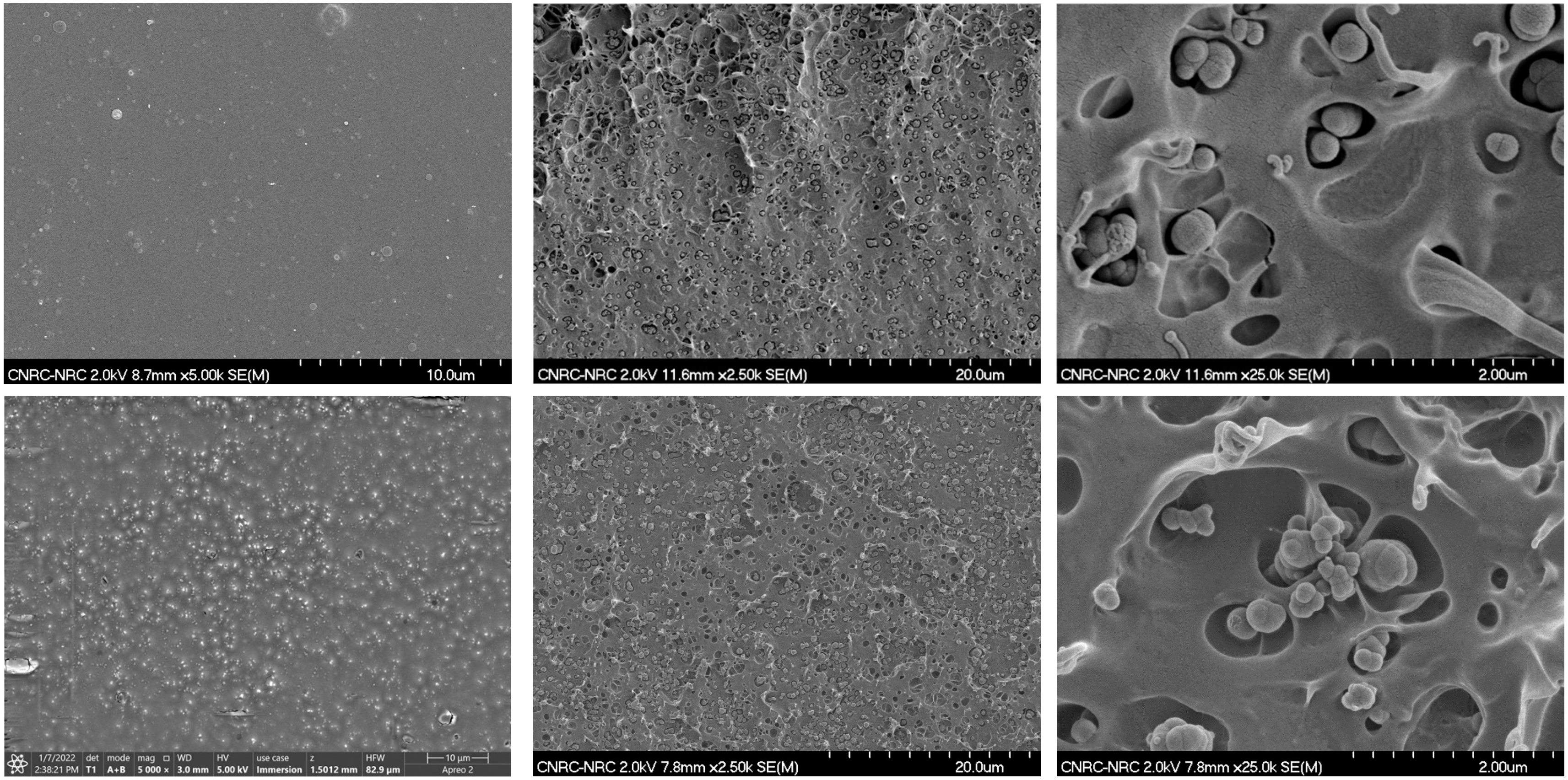
Therefore, at the same wt.% content, CB would accelerate the crystallization moment while hindering the crystal growing.



Characterization of PLA - TB cast films
SEM morphology



Characterization of PLA - TB cast films
SEM morphology

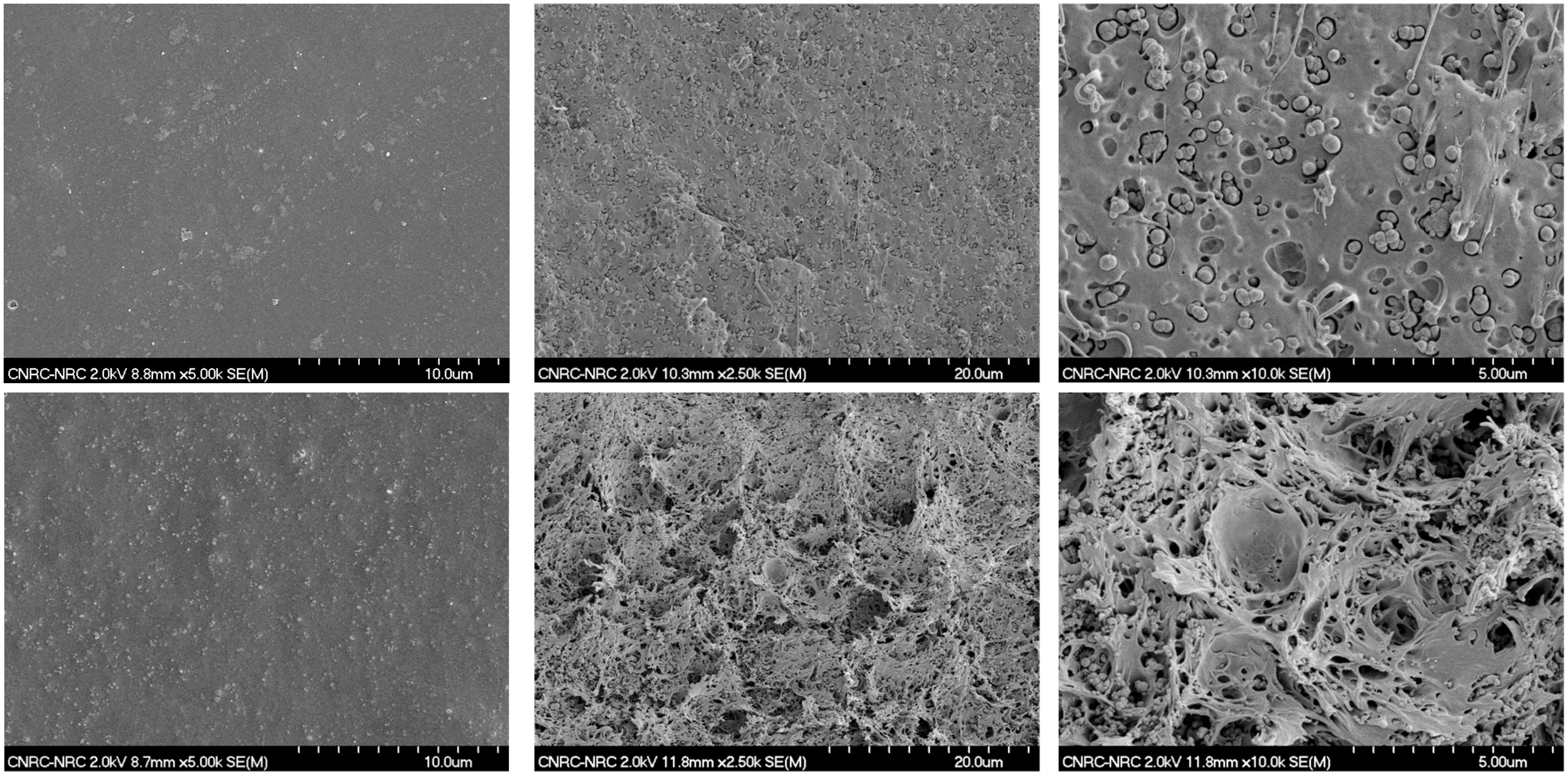


Characterization of PLA - TB cast films
SEM morphology

x 5,000 surface | **x 2,500 cross section** | **x 10,000 cross section**

20 wt.% TB

20 wt.% CB

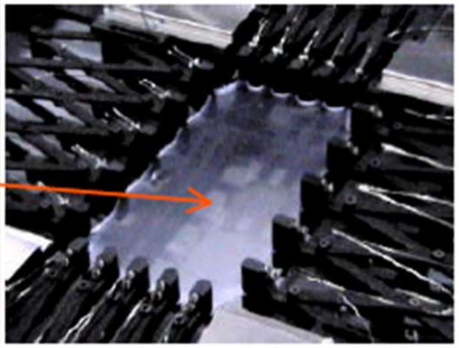


Bi-axial stretching of PLA-TB films

Objective:
To test the processability of PLA-TB cast films in bi-axial stretching process and to evaluate the performance of obtained stretched films using similar characterization methods as for cast films.

Stretching conditions:
Pre-heating time: 30 sec
Pre-heating temperature: 100 ^{o}C


Biaxial stretcher apparatus (Karo IV from Bruckner)


Clamping section of the stretcher

20 wt.%TB films obtained at different stretching rates

Bi-axial stretching
Characterization of stretched PLA-TB films

Mechanical testing:

- Tensile properties using ASTM D882 - 18: *Standard Test Method for Tensile Properties of Thin Plastic Sheeting*
  - *5 kN cell, 100 mm grips distance, 10 mm/min speed*
- All samples were conditioned at 23 ^{o}C, 50% RH and 40 hours and tested in Machine Direction (MD)
- PLA-TB bi-axial stretched films presented increasing tensile strength and modulus at increasing TB from 3 up to 20 wt.% (comparison at the same stretching ratio)
- PLA-TB bi-axial stretched films demonstrated similar and higher performance compared at pristine PLA
- PLA-TB bi-axial stretched films can replace pure PLA in applications such as laminations, industrial packaging etc.

Stretch ratio	**Thermal Black content wt.%**	**Thickness µm**	SD Thickness mm	**Tensile Modulus MPa**	SD TM MPa	**Tensile Strength MPa**	SD TS MPa	**Elongation %**	SD %
2x2	0	35.0	0.00	2232.6	158.6	43.7	5.1	5.8	2.3
5x5	0	12.0	0.00	1024.3	270.3	18.9	5.1	2.9	0.6
2x2	3	36.0	0.01	2242.3	157.1	37.3	2.5	3.2	0.4
5x5	3	10.0	0.00	1207.5	206.9	18.9	2.9	3.2	0.8
2x2	10	33.0	0.00	2702.6	397.8	44.9	6.6	2.5	0.2
5x5	10	19.0	0.02	1993.4	353.7	29.8	5.7	4.6	2.1
2x2	20	33.0	0.00	3301.1	340.1	51.6	2.0	2.6	0.3
5x5	20	10.0	0.00	1627.9	141.7	22.8	2.1	2.9	1.3
2x2	20 (CB)	41.0	0.00	3241.8	175.3	56.0	2.5	2.5	0.1
5x5	20 (CB)	17.0	0.00	1815.9	630.6	28.2	5.9	2.5	0.3

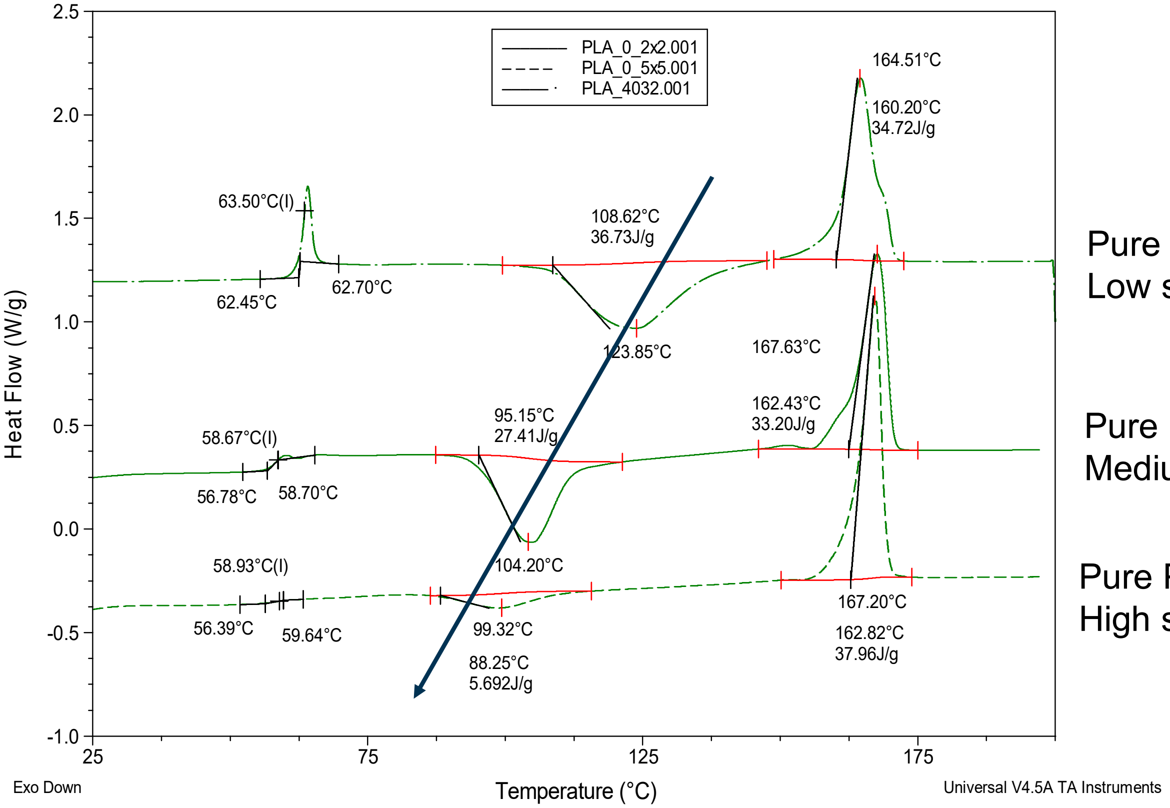
Bi-axial stretching
DSC of stretched PLA-TB films

Main observation:

The film crystallinity proved to increase with the level of stretching encountered during processing, i.e. from cast to stretched at 2x2 and up to 5x5.

The graph represents this phenomenon for pure PLA films.

This was observed for all the films, for all TB concentrations.



Pure PLA Cast
Low stretching

Pure PLA bi-axe 2x2
Medium stretching

Pure PLA bi-axe 5x5
High stretching

Bi-axial stretching
DSC of stretched PLA-TB films

Tg of bi-ax films: decreased to 59 ºC compared to cast films (64 ºC);
Tm of bi-ax films: similar or slightly lower compared to cast films
Tc of bi-ax films: decreased compared to cast films due to crystals developed rapidly during stretching at 100 ºC and 1 m/min

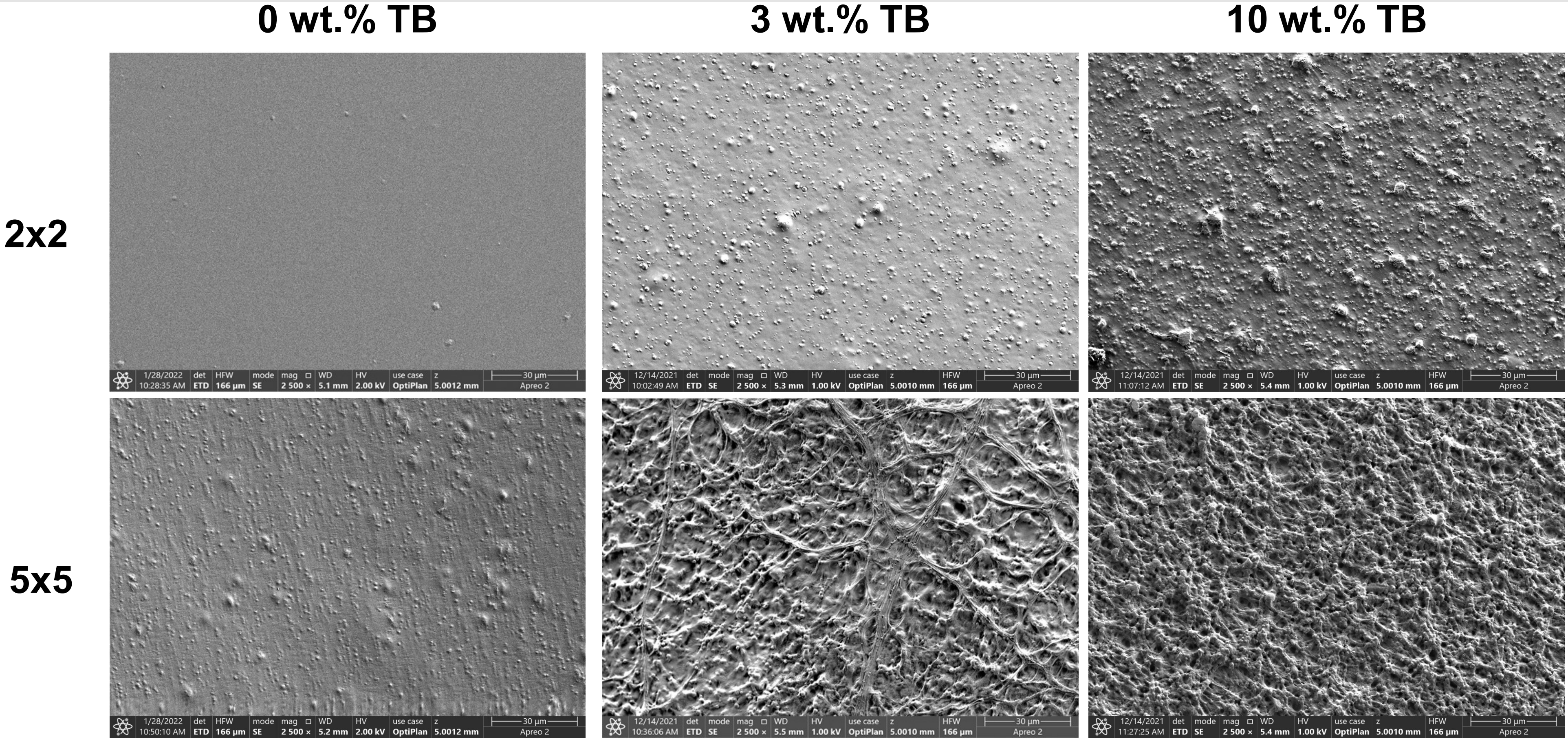
Stretch ratio	**TB Content wt.%**	**Heat 1: on bi-axially stretched films**							
		Tg ºC	ΔHc J/g	Xc %	Tc ºC	**Xm %**	ΔHm J/g	Tm ºC	X% From bi-ax
cast	0	63.5	33.7	**36.2**	123.8	**39.7**	36.9	169.0	NA
2 x 2	0	58.7	28.7	**30.9**	104.5	**38.9**	36.2	167.6	**8.1**
5 x 5	0	58.9	6.5	**7.0**	99.3	**44.1**	41	167.2	**37.1**
cast	0.03	63.7	34.2	**37.9**	113.6	**41.1**	37.1	168.8	NA
2 x 2	0.03	58.6	23.5	**26.1**	95.8	**39.4**	35.5	166.5	**13.3**
5 x 5	0.03	NA	1.7	**1.9**	82.6	**43.3**	39.1	166.5	**41.5**
cast	0.1	63.9	31.9	**38.1**	113.2	**39.4**	33	168.9	NA
2 x 2	0.1	58.3	15.1	**18.0**	92.1	**41.9**	35.1	166.3	**23.9**
5 x 5	0.1	NA	NA	**0.0**	NA	**46.2**	38.7	166.6	**46.2**
cast	0.15	57.7	27.1	**34.3**	105.1	**42.1**	33.3	167.5	NA
2 x 2	0.15	58.9	11.2	**14.2**	91.2	**43.8**	34.6	166.4	**29.6**
5 x 5	0.15	NA	NA	**0.0**	NA	**52.1**	41.2	166.7	**52.1**
cast	0.2	63.3	26.2	**35.2**	111.6	**43.1**	32.1	168.5	NA
2 x 2	0.2	58.4	8.3	**11.2**	90.4	**46.4**	34.5	166.2	**35.2**
5 x 5	0.2	NA	NA	**0.0**	NA	**55.8**	41.5	166.1	**55.8**
cast	0.2 (CB)	63.6	25.2	**33.9**	109	**33.9**	25.2	168.3	NA
2 x 2	0.2 (CB)	58.9	1.6	**2.2**	93.8	**44.2**	32.9	166.4	**42.1**
5 x 5	0.2 (CB)	NA	NA	**0**	NA	**49.3**	36.7	168.5	**49.3**

Crystallinity content increases with TB % and stretching degree.

High crystallinity was developed during stretching, that can further could conduct to pores formation while fingerprinting the films permeability performance

Bi-axial stretching
SEM of stretched PLA-TB films

x 2,500 surface

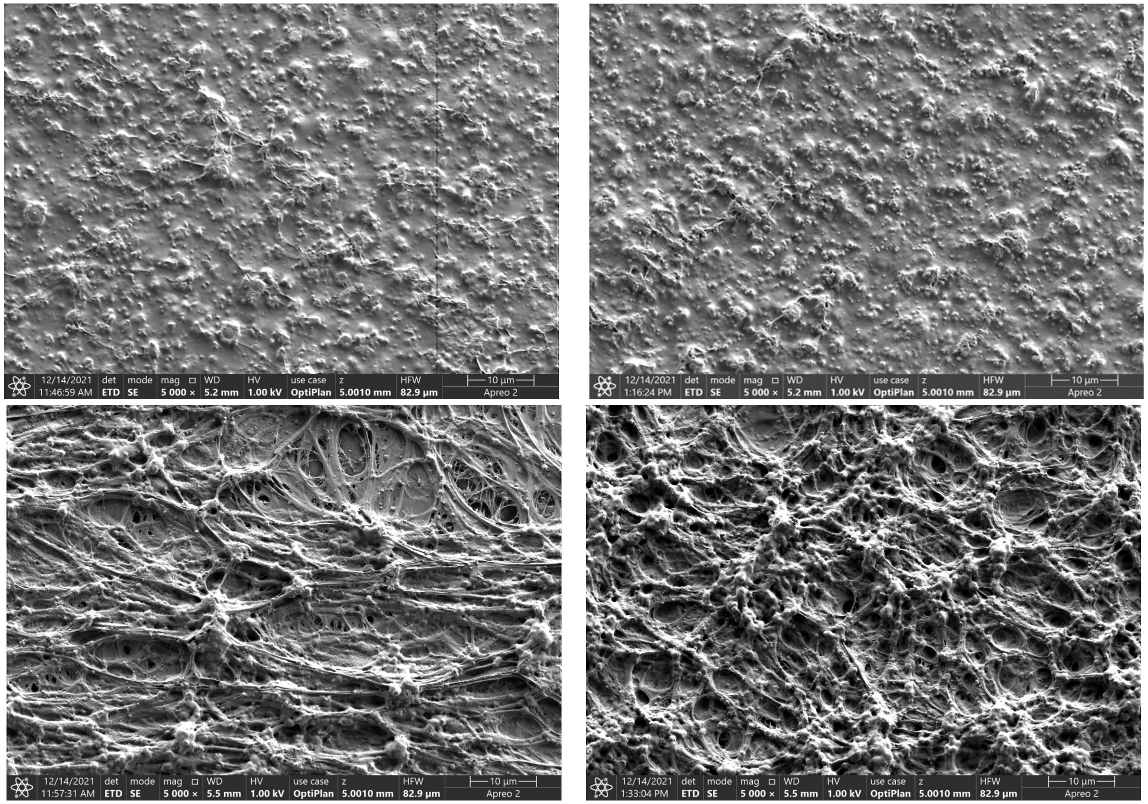


Bi-axial stretching
SEM of stretched PLA-TB films

15 wt.% TB **20 wt.% TB**

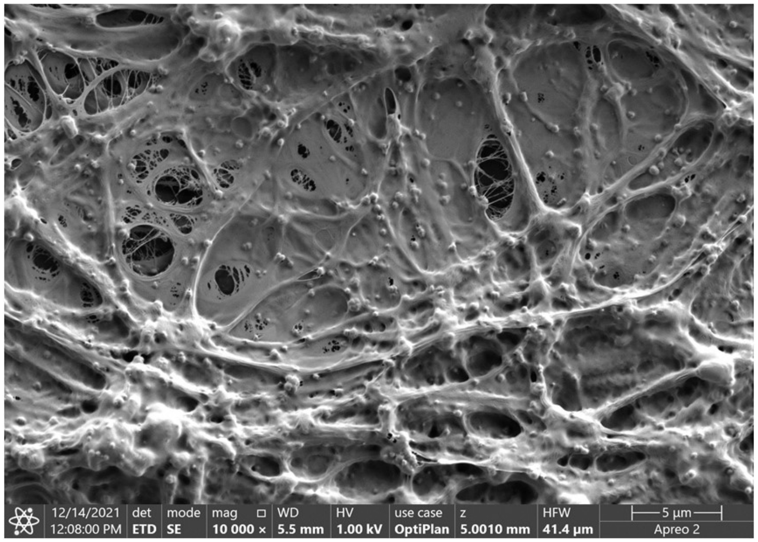
2x2

5x5



x 5,000 surface

5x5 15 wt.% TB
x 10,000 surface



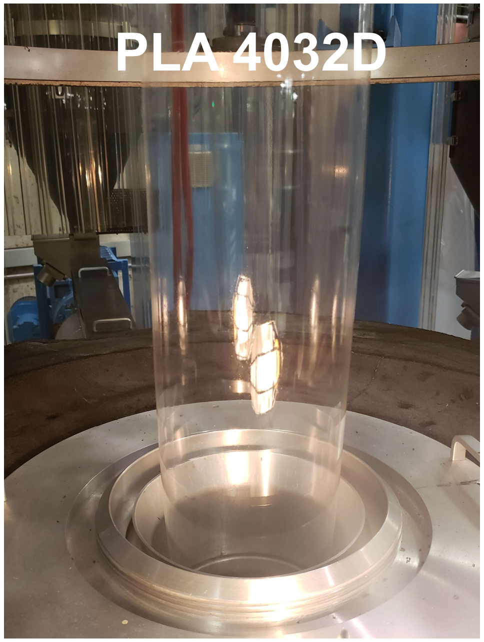
Pores formation in the film

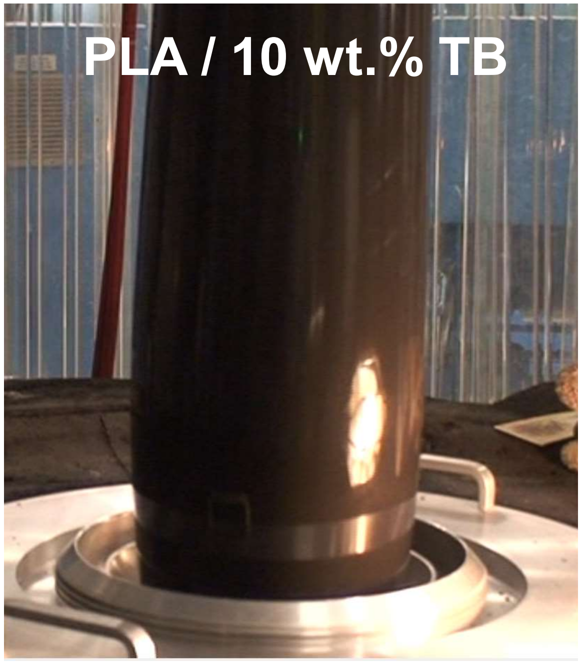
PLA - TB Films blowing

Objective:
To test two (2) optimal PLA-TB formulations in film blowing process using the NRC's semi-industrial scale film blowing line. The obtained films were tested using the same methods as for cast and bi-axial stretched films.

Brampton Engineering 100 mm

Formulation	Thickness
PLA 4032D reference	around 50 microns
10 wt.% TB	around 90 microns





Film blowing
Characterization of blown PLA-TB films

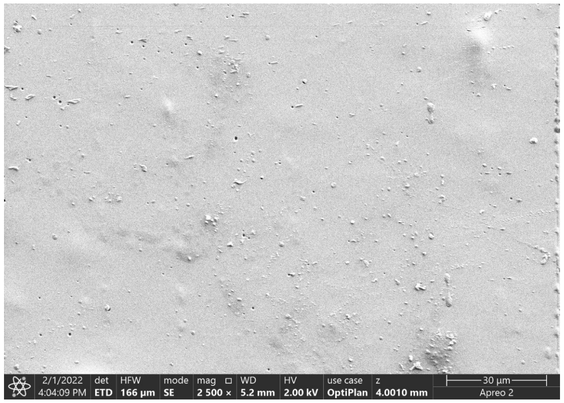
Tensile testing (ASTM D882 - 18):

- Samples were tested in MD direction
- In terms of TS & thickness, the blown film with 10 wt.% TB demonstrated adequate properties for single use packaging and protective films. The elongation is low, further improvement can be done. It has equivalent properties to the PLA / 20 wt.% TB film obtained in biaxial stretching.

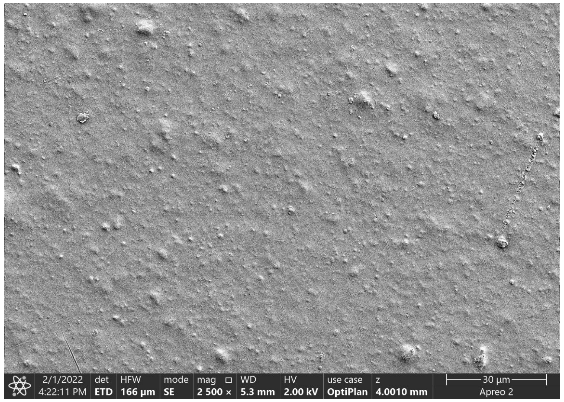
Blown film	**Thermal Black content wt.%**	**Thickness µm**	SD mm	**Tensile Modulus MPa**	SD TM MPa	**Tensile Strength MPa**	SD TS MPa	**Elongation %**	SD %
PLA-0, 4032D, Ref*	0	35	NA	NA	NA	48 MD (82 TD)	NA	5.7	-
PLA-2, 10 wt.% TB	10	11	0.01	3585.3	470.0	33.7	2.1	1.60	0.19

*https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8705587/

Morphology and Microstructure by SEM (x 2,500 surface):



0 wt.% TB



10 wt.% TB

Film blowing
Characterization of blown PLA & PLA-TB films

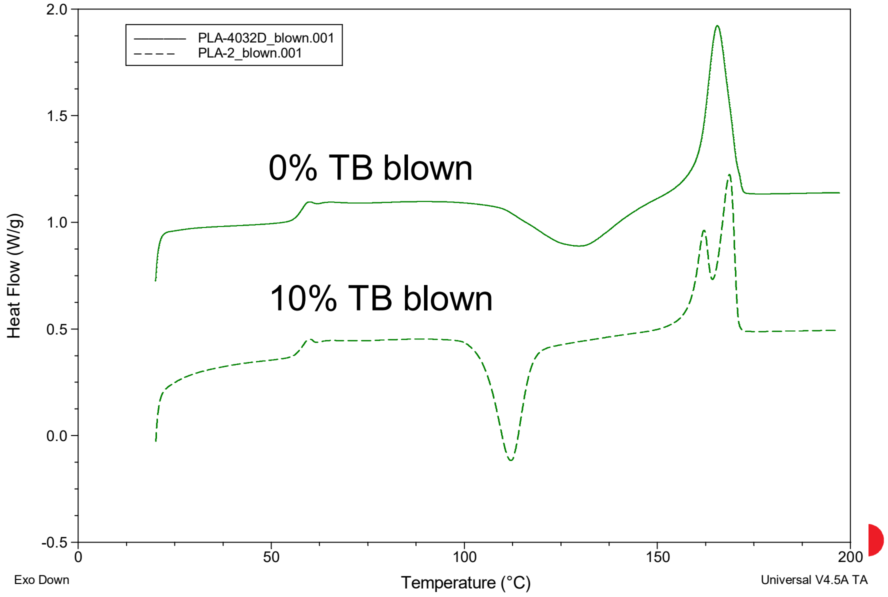
Differential Scanning Calorimetry analysis:

Only a heating cycle was applied with the purpose to evaluate the crystallinity in film blowing process.

The ΔHc and ΔHm of blown PLA films are roughly similar.

This means that the blown film obtained contain low levels of crystallinity, due to the low blow-up ratio used (BUR) to maintain the bubble, around 1.4.

Process	**TB Content wt.%**	**Heat : Behavior after casting**					
		Tgº C	ΔHc J/g	Tc ºC	ΔHm J/g	Tm1 ºC	Tm2 ºC
Cast	0	63.5	33.7	123.8	36.9	164.5	-
Blown		57.8	28.0	130.0	38.4	165.5	-
Cast	10	63.9	31.9	113.2	33.0	162.4	168.9
Blown		58.6	32.1	112.0	34.7	161.9	168.5



Biodegradability

Method:

- ASTM D5338
- Test at 58 °C, 55 days, 50% H.R.
- Monitor the Oxygen consumption
- Used references:

Positive: Cellulose-Sigma Aldrich-310697

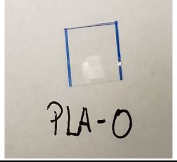
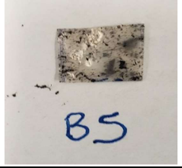
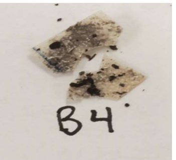
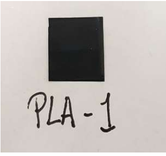
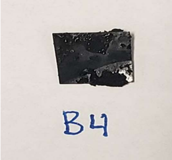
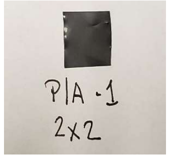
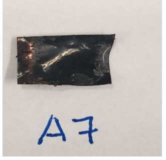
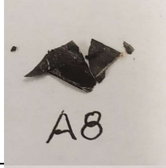
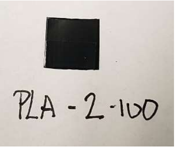
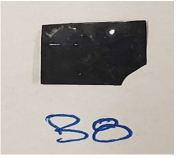
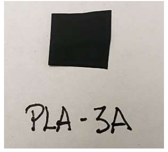
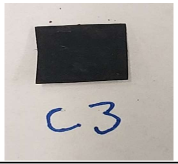
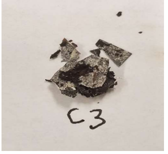
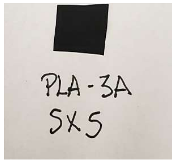
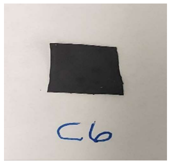
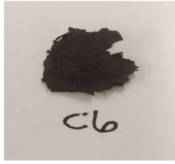
Pure PLA

- Compost: Peat and Bark Biofor®

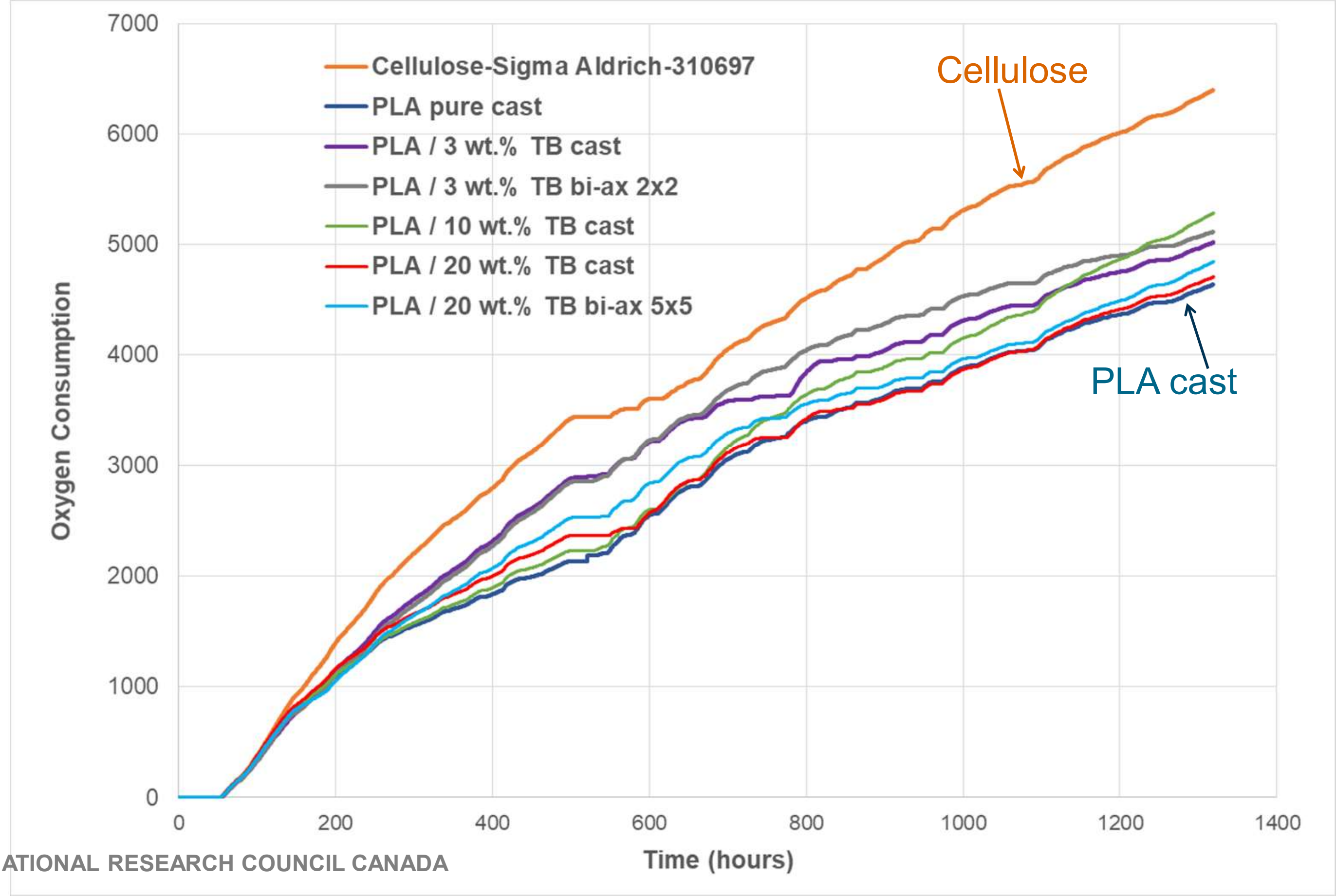
3 samples were tested from each film. The samples were monitored at an time interval of 20 days (see table).

The final visual aspect - the level of disintegration is presented in the last column.

All the tested PLA-TB films disintegrated in a similar way compared to pristine PLA.

Phases :	Start-up	1st validation	2nd validation	End of the test
Date :	0 days	20 days	37 days	55 days
Name	PHOTOS			
PLA / 0 wt.% TB Cast				
PLA / 3 wt.% TB Cast				
PLA / 3 wt.% TB Bi-axe 2x2				
PLA / 10 wt.% TB Cast				
PLA / 20 wt.% TB Cast				
PLA / 20 wt.% TB Bi-axe 5x5				

Biodegradability PLA-TB films



Oxygen consumption is presented as a function of time.

Oxygen consumption is proportional to CO_2 produced during the samples degradation.

All PLA/TB films demonstrate an O_2 consumption equal or slightly higher than the pristine PLA cast film and less compared at positive control, the cellulose.

All PLA/TB films present similar Aerobic Biodegradation, slight differences are due to TB content, porosity and the thickness of samples.

Barrier properties of PLA - TB films

			ASTM D-3985		ASTM F2714-08 2013	ASTM F-1249-06	
Sample	**TB content** wt.%	**Film Thickness µm**	**OTR cc/m^2.day**	SD	**OTR cc/m^2.day**	**WVTR g/m^2.day**	**SD**
PLA 4032D NatureWorks® LLC*	0	25	675	-	-	380	-
Cast	3	121	148	1	NA	40.1	0.9
Bi-axe 2 x 2	15	40	566	67	NA	123.2	23.6
Bi-axe 3.5 x 3.5	15	20	7721	1847	NA	337.5	34.6
Bi-axe 5 x 5	20	10	NA	NA	65493, 1542, 166554	781.5	76.6

* Data on PLA 4032 permeability from TDS from manufacturer

OTR & WVTR increased with films crystallinity. Crystallinity development in PLA-TB films depends on parameters used for cast and bi-ax stretching processes and TB content. The PLA-TB crystallinities can be fine-tuned to obtain other values for OTR and WVTR

Conclusions OTR:

An industry rule-of-thumb is that a film material is considered a **"high oxygen barrier" if its OTR is less than 15.5 cc/m^2/day**.

Pristine reference PLA film: has **a good permeability to oxygen (*)**, i.e. 675 cc/m^2/day.

PLA/TB films: OTR values increased with TB content and the stretching, i.e. proportionally to the crystallinity content of tested films.

PLA/3 wt.% TB cast-film (121 µm) has a low permeability to O_2 while Bi-ax PLA/15 wt.% TB, 2x2 (40 µm), has an OTR similar to pure PLA.

Conclusions WVTR:

A polymer film is considered **water vapor barrier for WVTR values of 4 - 10 g/m^2.day**

Pristine reference PLA film: has rather good permeability to water vapors, i.e. 380 g/m^2.day.

PLA/3 wt.%TB has a low WVTR but this value is a function of film thickness, 121 µm.

PLA/TB films: WVTR values increased with TB content and the stretching, but remained near the value of PLA reference film.

Cast, bi-axial stretched, and blown films Optical properties

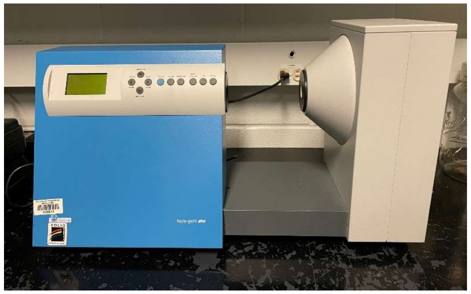
Transparency (transmittance):
- Measurement according to ASTM D1746-09
- Haze-guard plus from BYK Gardner was used
  - No sample→ 100% transparency
  - Blocked light path → 0% transparency

Conclusions:
- All cast and blown films with fillers have 0 transparency
- For bi-axial stretched films with filler:
  - At low stretch ratio (2x2) films are not transparent independent of filler content
  - At high stretch ratio (5x5) and minimum filler content semi-transparent films an be achieved
- High potential to block the UV

Biax film	Average T Value	SD
PLA_0_2x2	95.7	0.0
PLA_0_5x5	95.7	0.1
PLA_1_2x2	5.6	1.3
PLA_1_5x5	63.4	4.3
PLA_2_2x2	0.0	0.0
PLA_2_5x5	12.6	2.3
PLA_3a_2x2	0.0	0.0
PLA_3a_5x5	1.0	0.3
PLA_3b_2x2	0.0	0.0
PLA_3b_5x5	0.4	0.3
PLA_5_2x2	0.0	0.0
PLA_5_5x5	15.2	9.1

Blown film	Average T Value	SD
PLA_0	95.0	0.1
PLA_2	0.0	0.0

Cast film	Average T Value	SD
PLA_0	95.5	0.1
PLA_1	0.0	0.0
PLA_2	0.0	0.0
PLA_3a	0.0	0.0
PLA_3b	0.0	0.0
PLA_4	0.0	0.0
PLA_5	0.0	0.0



Conclusions

Performance vs. thickness of PLA / TB films from this project – for industrial applications:

- PLA / TB films from cast extrusion: Thickness = 140 - 120 µm, TS MD = 40 - 45 MPa, ε MD = 3 %
- PLA / TB films from biaxial stretching: Thickness = 10 - 35 µm, TS MD = 22 (2x2) - 50 (5x5) MPa, ε MD = 3-5 %
- PLA / TB from blown film process: Thickness = 11 µm, TS MD = 34 MPa, ε MD = 1.6 % (process to be optimized)

Commercial Biodegradable Mulch Films:

Mater-Bi® - Novamont
Starch material + compostable polyesters
Thickness = 15 µm
TS (MD/TD) = 41.0/34.2 MPa
ε = 400% MD

Ecovio® - BASF
Biodegradable Ecoflex + PLA
Thickness = 20 µm
TS (MD/TD) = 31.2/22.5 MPa
ε = 100% MD

Commercial PURE PLA films: (TDS data)
T-shirt bags and waste bags, thin film for laminate applications and packaging
Thickness: 60↘30↘15, TS MD = 30↗47↗100 MPa, ε MD = 450↘290↘180%

According to EN 13655: an elongation of 180% is expected for black conventional mulches with thickness less than 30 µm.

Elongation of PLA / TB films can be easily improved by adding, for example, Ecoflex (BASF)

PLA / TB films demonstrated to be appropriate for many types of applications.

PLA / TB could be a lower-cost choice compared to pristine PLA (TB price is lower).

THANK YOU!

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