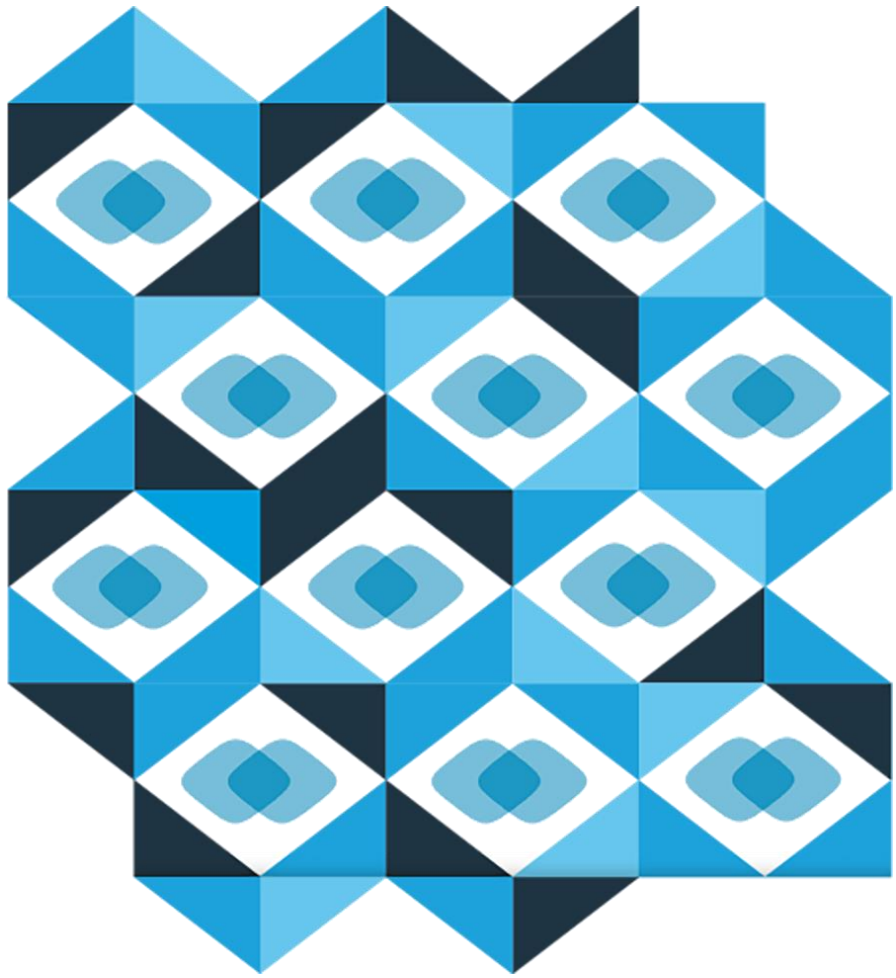
Recyclability Report

RecyClass Recyclability evaluation protocol for PE films

Client: Polymateria
Date: 18/02/2021
Report Number: IMP03835-LR-V5

Report Author: Dr Michail Kalloudis, Ceng, MIMMM



Impact Solutions, 16 Abbotsinch Road, Grangemouth, FK3 9UX
www.impact-solutions.co.uk

Summary

Impact Solutions were asked to undertake testing on the compatibility of polyethylene (PE) containing Polymateria's Biotransformation additive technology within the recycling process.

The tests were carried out in independent laboratories that run analyses on different samples, following the procedures of the RecyClass Recyclability Evaluation Protocol for PE films.

PE films make up a large proportion of the food (primary) packaging as well as secondary packaging, such as shrink and bubble wrap. They help in keeping goods fresh and prolong their shelf life, whilst also providing protection during transport. Despite being a ubiquitous plastic packaging product, their availability of recycling remains inconsistent depending upon the geographical region within Europe. Nevertheless, where they are collected, sorted, and recycled it is often in high volumes making it necessary for new or innovative PE films to be compatible.

Polymateria is actively working on innovative packaging solutions that support the recycling processes. It is because of this that Polymateria engaged with IMPACT SOLUTIONS to perform the RecyClass protocol upon these Polymateria-PE films to evaluate the effect of this new packaging technology to help the industry to ensure recyclability of new products entering the market.

The findings show that PE films containing Polymateria's technology has no impact on the recycling process nor on the resulting recycled material when assessed against the RecyClass Recyclability Evaluation Protocol for PE films.

Contents

1. Testing Protocol

The testing described within this report has been carried out based on the "RecyClass Recyclability Evaluation Protocol for PE Films" version 1.0 published on the 6th of September 2018.

The purpose of the protocol is to reproduce the recycling process at a small scale to determine the suitability of a material for PE film recycling streams.

Figure 1 below outlines the test protocol followed.

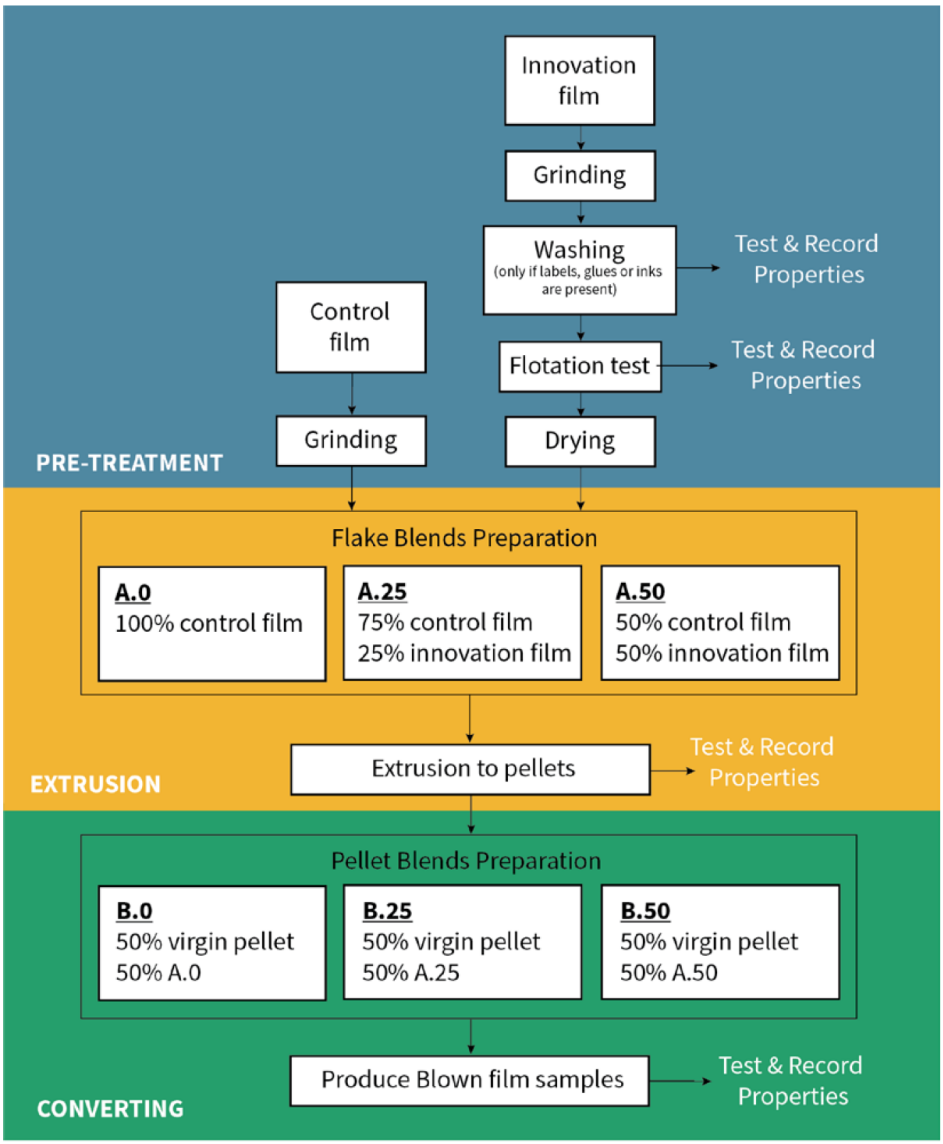


Figure 1: RecyClass Methodology

2. Materials Received

The following materials were received by the Impact Solutions and logged into the sample reception as shown in Table 1.

Material	Impact code	Polymateria code
Control Film	MT/GM/4046	PLM-G-01
Control Film	MT/GM/4047	PLM-G-01
Control Film	MT/GM/4048	PLM-G-01
Innovation Film	MT/GM/4049	PLM-G-02
LLDPE Pellet	MT/GM/4050	22FA002
LLDPE Pellet	MT/GM/4051	22FA002
LDPE Pellet	MT/GM/4052	JF19010

Table 1: Materials Received.

During the testing protocol a number of other materials were created using the received materials and they are shown, along with their naming conventions in table 2.

Pellet code	Polymateria Identity	PLM MB (%)	Resin
A.0	PLM-P-005	0%	PLM-G-01 (100%)
A.25	PLM-P-006	0.50%	PLM-G-01 (75%) PLM-G-02 (25%)
A.50	PLM-P-007	1%	PLM-G-01 (50%) PLM-G-02 (50%)
B.0	PLM-F-001	0%	Virgin pellet (50%) PLM-P-005 (50%)
B.25	PLM-F-002	0.25%	Virgin pellet (50%) PLM-P-006 (50%)
B.50	PLM-F-003	0.50%	Virgin pellet (50%) PLM-P-007 (50%)

Table 2: Pellet blend composition and naming

Where virgin pellet was used for pellet codes B.0 to B.50, this was a mix of 85% b/w LLDPE Pellet (22FA002) and 15% b/w LDPE (JF19010).

Throughout this report the materials will be referred to by the Polymateria Identity shown in tables 1 and 2.

3. Testing Protocol – Pre-Treatment Steps

3.1 Grinding

The films (control and innovation) were granulated using the following method.

3.1.1. Densification

This was performed by layering the films into a mould and compression moulding them at 135C for 5 minutes in order to produce a densified product suitable for granulation.

3.1.2. Granulation – 10mm screen

The densified films were initially passed through a 10mm granulation screen using a Cumberland Granulator (Figure 2).

The machine was stripped and cleaned between granulation of the control and innovation films to avoid cross contamination.

Figure 2: Granulator with 10mm screen

3.1.3. Granulation – 3mm screen

Due to the barrel size of the lab extruder, the material was further size reduced through a 3mm screen as shown in Figure 3 below.

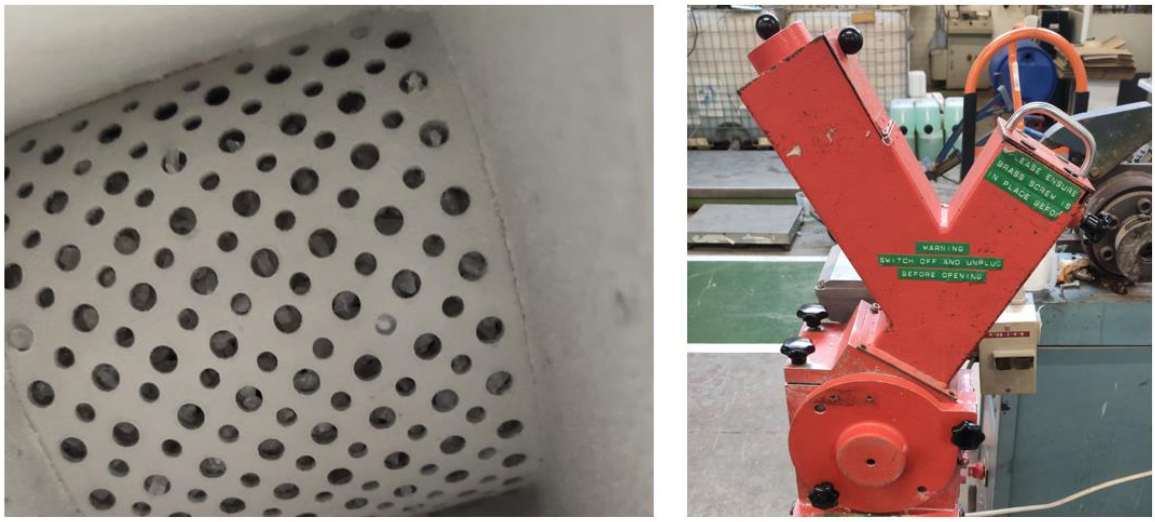


Figure 3: 3mm granulation screen

Following granulation, the material was in a suitable form for pellet production. Figure 4 shows the appearance of the film after size reduction.

Figure 4: Control film (PLM-G-01) after size reduction

3.2 Flotation test and Drying

Both PLM-G-01 and PLM-G-02 were subjected to a floatation test and drying following the size reduction step.

Both materials were tested for floatation as follows;

1. 50g of the material was weighed out.
2. 250ml of room temperature tap water was measured into a 400ml beaker.
3. The pellets and a stirrer bar were added to the beaker and set on a plate.
4. The heater was not turned on and the stirring set to 1000rpm.
5. The mixture was stirred for 10 minutes.
6. There was no observable difference in the before and after appearance of the water, nor of the materials. All materials floated.

Following the flotation step both materials were dried at 60C for 12 hours. The results are shown in Table 3 below. There is no significant difference in the rate of drying of the two materials.

Material	Time	Mass (g)	Time	Mass (g)	Time	Mass (g)
PLM-G-01	0H	241.1	6H	120.5	12H	120.2
PLM-G-02	0H	284.6	6H	171	12H	162

Table 3: Drying results

4. Pellet Production

The films were compounded and extruded into pellet as shown in Table 4.

Pellet code	Polymateria Identity	PLM MB (%)	Resin
A.0	PLM-P-005	0%	PLM-G-01 (100%)
A.25	PLM-P-006	0.50%	PLM-G-01 (75%) PLM-G-02 (25%)
A.50	PLM-P-007	1%	PLM-G-01 (50%) PLM-G-02 (50%)

Table 4: Pellet production

The films were extruded using a Prism extruder shown in Figure 5 below.

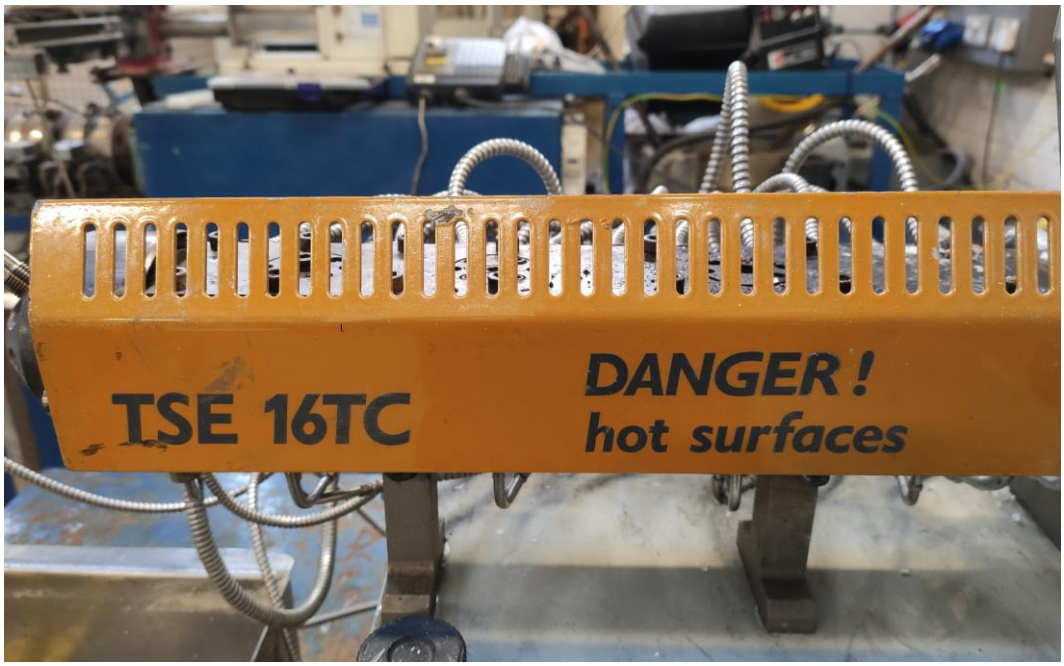


Figure 5: PRISM TSE 16TC extruder

The extruder is a twin-screw extruder with a 16mm barrel. It is fed by a Brabender feeder with the extrudate exiting a single strand die head into a 2m water bath, before being pelletised.

Figure 6: Extruder, bath and pelletiser

All four pellet codes were run at the following parameters;

- Zone 1: 125 °C
- Zone 2: 140 °C
- Zone 3: 160 °C
- Zone 4: 180 °C
- Zone 5: 200 °C
- Processing Temperature: 195 °C ±3 °C

The feed was adjusted to produce a targeted torque of 8Nm. This is however variable based on several properties, including the melt flow of the relevant material and the particle size distribution.

All materials produced a nominal run rate of 600g per hour. 3 kg of each material was produced giving an approximate run time of 5 hours for each material. There were no observable fluctuations in processing torque or pressure on any of the materials processed during this testing.

5. Pellet Properties

Following production of the pellets, testing was carried out as per Table 5 below.

Assessment	Method	Benchmark Recommendation
Bulk Density (kg/m3)	Bulk density apparatus as per ISO 61:2000 and ASTM D1895-96	No less than 500 kg/m3
Melt Flow Rate (g/10 min)	ISO 1133-1	< 0.5 g/10min delta to control value
Ash content (%)	ISO 3451-1 by TGA	Record
Gas content (% weight)	TGA Weight loss at 120ºC	Record
Differential Scanning Calorimetry (ºC)	ISO 11357- 3	Melt Temperature < 150 ºC
Impurities content	Visual inspection	Record
Surface appearance	Visual inspection	Record
Volatiles (%)	Air dried pellets exposed to 160ºC for 10 minutes	< 1.0%
Reflection Colour	(CIE L*, a* b*)	Record
Average torque recorded during extrusion in (Nm)	Less than 25% higher Δ in torque compared to 100% control.	No more than 25% delta to control

Table 5: Pellet properties evaluation

Results were as follows in Table 6. Visual pictures of the pellets for each blend are shown in Figure 7 to Figure 9 below.

Assessment	Unit	PLM-P-005	PLM-P-006	PLM-P-007
Bulk Density	Kg/m^3	439 ± 15	441 ± 2	442 ± 16
Melt Flow	g/10min @ 190°C 2.16kg	0.71	0.73	0.82
Ash	%	0	0	0
Gas Content	%	0.13	0.13	0.13
DSC	°C	123.4	126.1	125.1
Impurities	N/A	none	none	none
Surface	N/A	normal	normal	normal
Volatiles	%	0.02	0.2	0.3
Reflection	CIE L*, a* b*	36.02/2.72/2.47	32.18/4.86/2.6	29.39/9.2/3.68
Torque	Nm	8.0	8.3	8.5

Table 6: Pellet Properties results

The pellets meet all the requirements of the standard, other than the properties for bulk density. However, this is highly dependent on the thickness of the strand and method of palletisation. All the innovation materials are nominally the same bulk density as the control material.

Figure 7: PLM-P-005

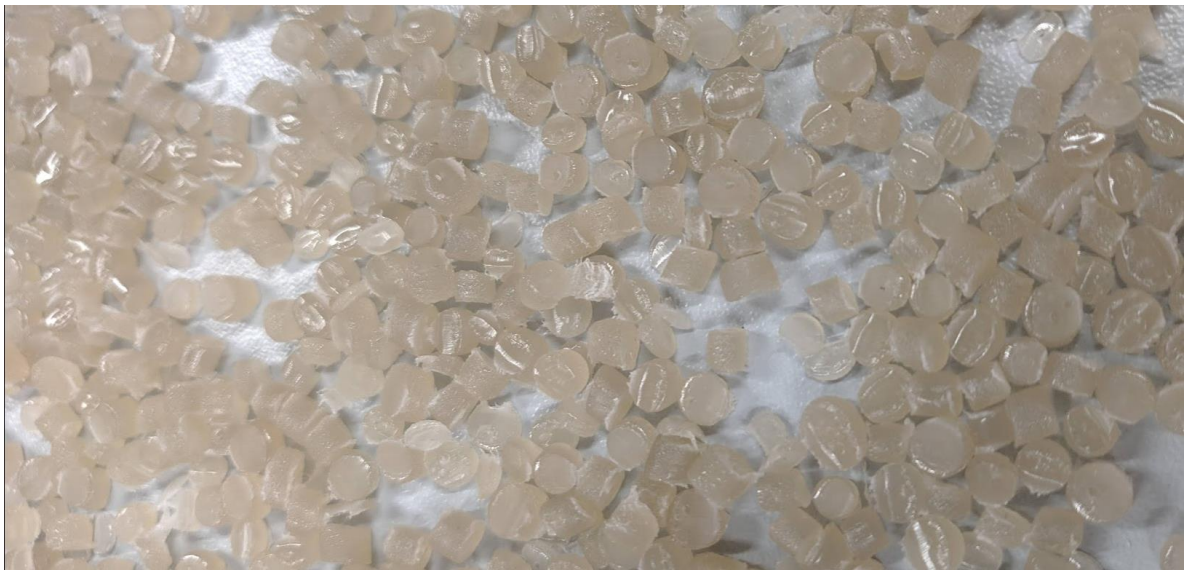


Figure 8: PLM-P-006

Figure 9: PLM-P-007

6. Blown Film Production

6.1 Pellet production

The pellets produced (PLM-P-005 to PLM-P-007) were further used to create the materials listed in Table 7 below.

Table 7: Composition of pellets for blown film production

Pellet code	Polymateria Identity	PLM MB (%)	Resin
B.0	PLM-F-001	0%	Virgin pellet (50%) PLM-P-005 (50%)
B.25	PLM-F-002	0.25%	Virgin pellet (50%) PLM-P-006 (50%)
B.50	PLM-F-003	0.50%	Virgin pellet (50%) PLM-P-007 (50%)

The pellets were produced using the same equipment as for the A pellets. The Virgin Pellets used were a blend of 85% b/w LLDPE (22FA002) and 15% b/w LDPE (JF19010). These pellets were mixed with the PLM pellets and extruded and pelletised ready for film blowing. 5kg of each blend was produced, with an extrusion time of around 5 hours per material.

All materials were processed using the same parameters as used for the A pellets and no observable differences were seen during the processing of the four materials.

6.2 Blown film production

The pellets produced (Table 7) were sent to Queen's University Belfast (QUB) to be blown into film with the following parameters:

- Blown film with a blow-up ratio > 2.5
- melt temperature of 200 – 230 °C
- thickness benchmark of 25 µm.

All four materials were blown into film without problems or noticeable differences in processing.

Films were received back at Impact, as shown below in Figure 10.

Figure 10 Films as received back by Impact

7. Blown Film Properties

The films were subjected to testing as shown in Table 8 below.

Assessment	Standards	Benchmark Recommendation
Thickness (mm)	ISO 4593; DIN 53370	25 µm
Tear Strength (TD**) (g)	DIN EN ISO 6383; DIN EN ISO 1974	No more than 25% delta to control
Tear Strength (MD***) (g)	DIN EN ISO 6383; DIN EN ISO 1974	N/A
Tensile Strength (TD) (MPa)	DIN EN ISO 527	N/A
Tensile Strength (MD) (MPa)	DIN EN ISO 527	N/A
Elongation at Yield (TD) (%)	DIN EN ISO 527	N/A
Elongation at Yield (MD) (%)	DIN EN ISO 527	N/A
Dart Impact (g)	ISO 7765	N/A
Haze (%)	DIN EN ISO 13468	Record. Increase of haze will lower the visual aspects
Gels and Specks (amount)	5 samples of 100 cm^2 for a gel and specks count greater than 200 µm seen by the naked eye at 30 cm from sample. The number will be recorded but no standard required.	Record. All gels & specs will weaken the film quality
Surface Appearance	N/A	Record. Limit the end use application.

Table 8 Film testing specifications

The results of the testing are shown in Table 9 below.

Test	PLM-F-001	PLM-F-002	PLM-F-003
Thickness (um)	25	26	23
Tear Strength (TD**) (g)	230	231	168
Tear Strength (MD***) (g)	196	206	175
*Tensile Strength (TD) (MPa)	17.5	19.5	17.9
*Tensile Strength (MD) (MPa)	17.7	18	14.3
*Elongation at break (TD) (%)	586	522	616
Elongation at break (MD) (%)	394	417	367
Dart Impact (g)	102	93	76.0
Haze (%)	9.7	10.4	7.6
Gels and Specks count / (100 x 100)cm2	878	899	711
Surface Appearance	No change in films B25, B50compared to control film for grey scale test. Overall surfaces of all the films seem to have track marks coming from the sizing rollers during blown film production and not due to the materials. No visible black specs or foreign contamination present.		

Table 9 Testing results

The appearance of film PLM-F-002 is shown in Figure 11 below.

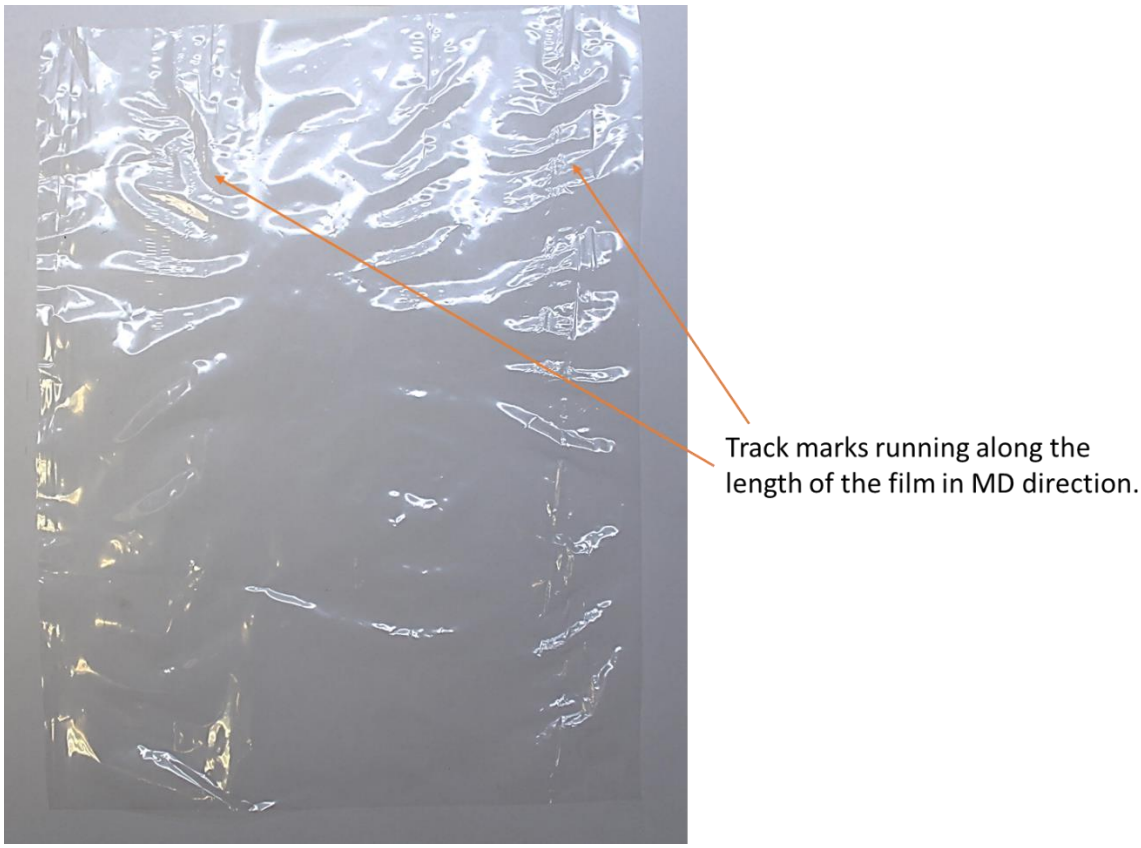


Figure 11 Appearance of blown film

8. Discussion

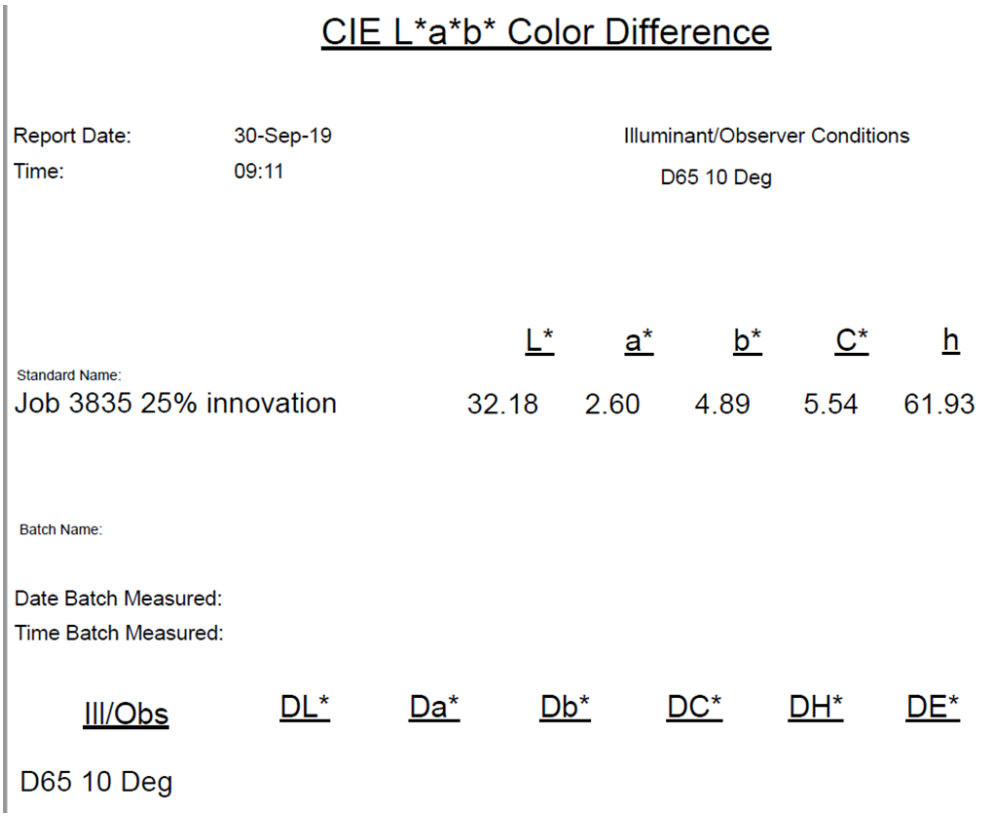
The testing results show that the innovation material has had no effect on the mechanical or visual quality of the materials. As such, the innovation material tested for the purposes of this report can be introduced to a recycling supply chain with no adverse effect on the quality of the recycled film produced as a result.

Appendix 1 - Pellet properties - tests

Colour Tests:

A Datacolor Select QC colorimeter was used for the analysis. The colorimeter was automatically calibrated on standard white. The Illuminant D65 at an angle of 10 degrees was chosen for the tests.

The CIE Lab coordinates were capture for each test. 3 repeats were captured per test and the average result is reported only. Figures below present the raw data captured from the Data color software:



CIE L*a*b* Color Difference

Report Date: 30-Sep-19
Time: 09:11

Illuminant/Observer Conditions
D65 10 Deg

	L*	a*	b*	C*	h
Standard Name:					
Job 3835 25% innovation	32.18	2.60	4.89	5.54	61.93

Batch Name:

Date Batch Measured:
Time Batch Measured:

Ill/Obs	DL*	Da*	Db*	DC*	DH*	DE*
D65 10 Deg						

Figure 12. CIE Lab test results, PLM-P-006

CIE L*a*b* Color Difference

Report Date: 30-Sep-19
Time: 09:10

Illuminant/Observer Conditions
D65 10 Deg

	L*	a*	b*	C*	h
Standard Name:					
Job 3835 50% innovation	29.39	3.68	9.20	9.91	68.23

Batch Name:

Date Batch Measured:
Time Batch Measured:

Ill/Obs	DL*	Da*	Db*	DC*	DH*	DE*
D65 10 Deg						

Figure 13. CIE Lab test results, PLM-P-007

CIE L*a*b* Color Difference

Report Date: 18-Sep-19
Time: 15:53

Illuminant/Observer Conditions
D65 10 Deg

	L*	a*	b*	C*	h
Standard Name:					
Job 3835 colour test	36.02	2.47	2.72	3.68	47.74

Batch Name:

Date Batch Measured:
Time Batch Measured:

Ill/Obs	DL*	Da*	Db*	DC*	DH*	DE*
D65 10 Deg						

Figure 14. CIE Lab test results, PLM-P-005

Ash and Gas Content via Thermogravimetric Analysis (TGA)

A TGA unit from NETZSCH, Germany, model F3 Tarsus, calibrated by the supplier engineers was used for the analysis of the evolved gases and the ash content. Approximately 10-20 mg of specimens were used per sample and placed in Alumina crucibles for analysis. The temperature program was the following:

- Heat from RT to 120 °C @10 °C/min, under nitrogen
- Isothermal at 120 °C for 5 min, under nitrogen
- Heat from 120 to 900 @10 °C/min, under nitrogen

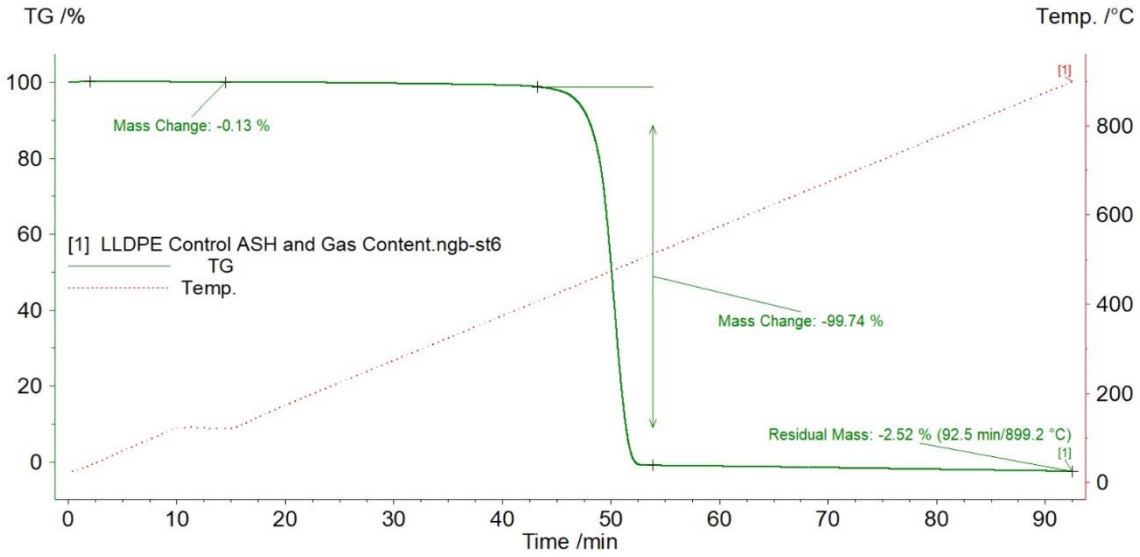


Figure 15. TGA thermogram, LLDPE control material, PLM-P-005

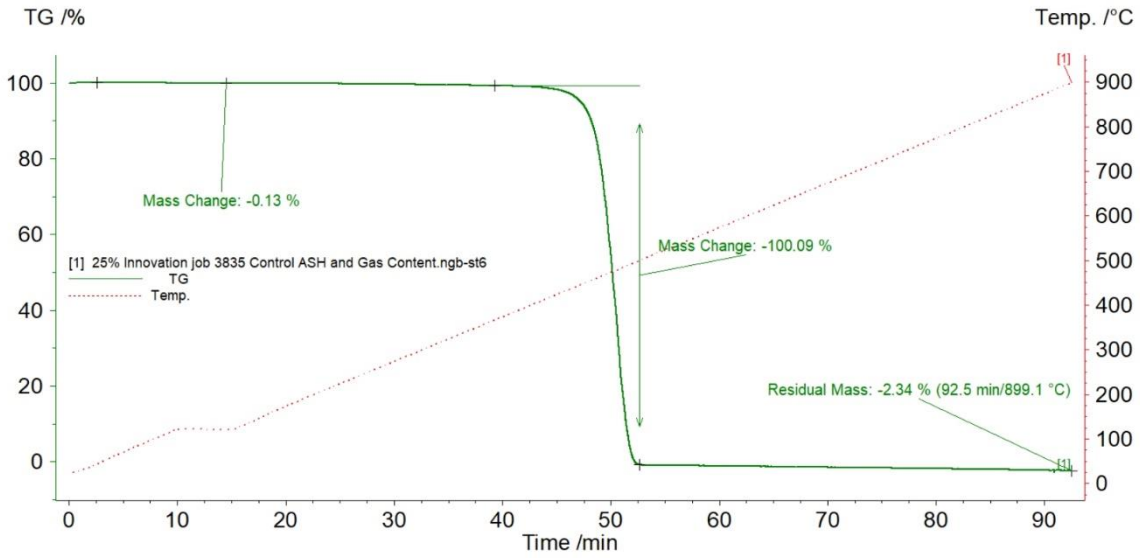


Figure 16. TGA thermogram, 25% Innovation, PLM-P-006

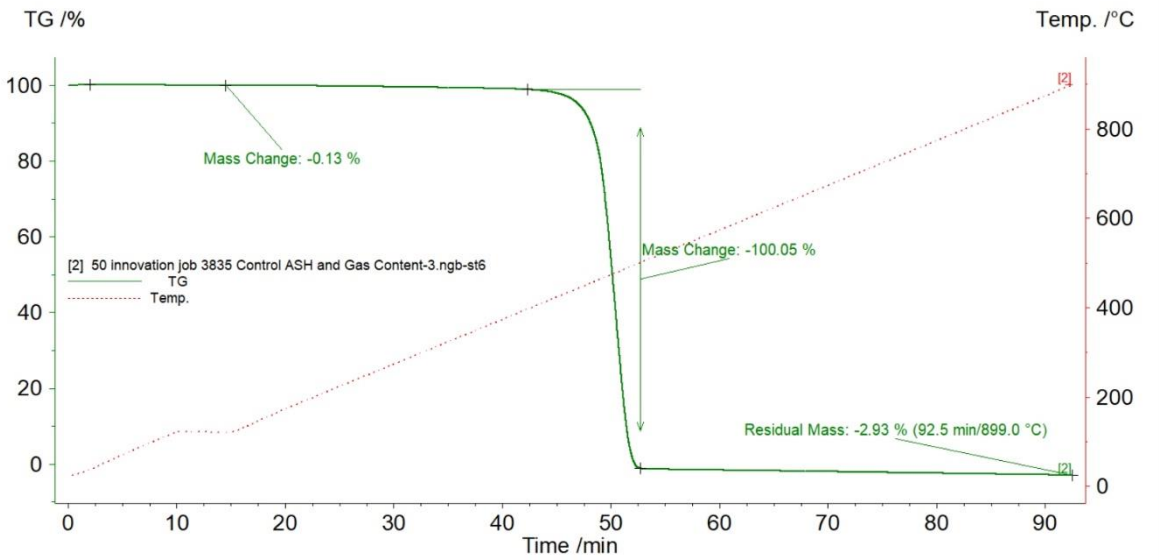


Figure 17. TGA thermogram, 50% innovation, PLM-P-007

Melting Temperature via Differential Scanning Calorimetry (DSC)

A DSC unit from NETZSCH, Germany, model 214 Polyma, calibrated internally using NIST/LGC traceable standards and covered UKAS scope of accreditation was used for the melting temperature analysis. Approximately 10-20 mg of specimens were used per sample and placed in aluminium crucibles for analysis. The heat program was the following:

- Heat from 30 to 200 °C @20 °C/min, under nitrogen
- Isothermal at 200 °C for 3 min, under nitrogen
- Cool from 200 °C to 30 °C @20 °C/min, under nitrogen
- Heat (2^{nd} heat) from 30 to 200 °C @20 °C/min, under nitrogen

The melting peak temperature was captured from the second heat cycle. The Proteus software from NETZSCH was used to analyze the results.

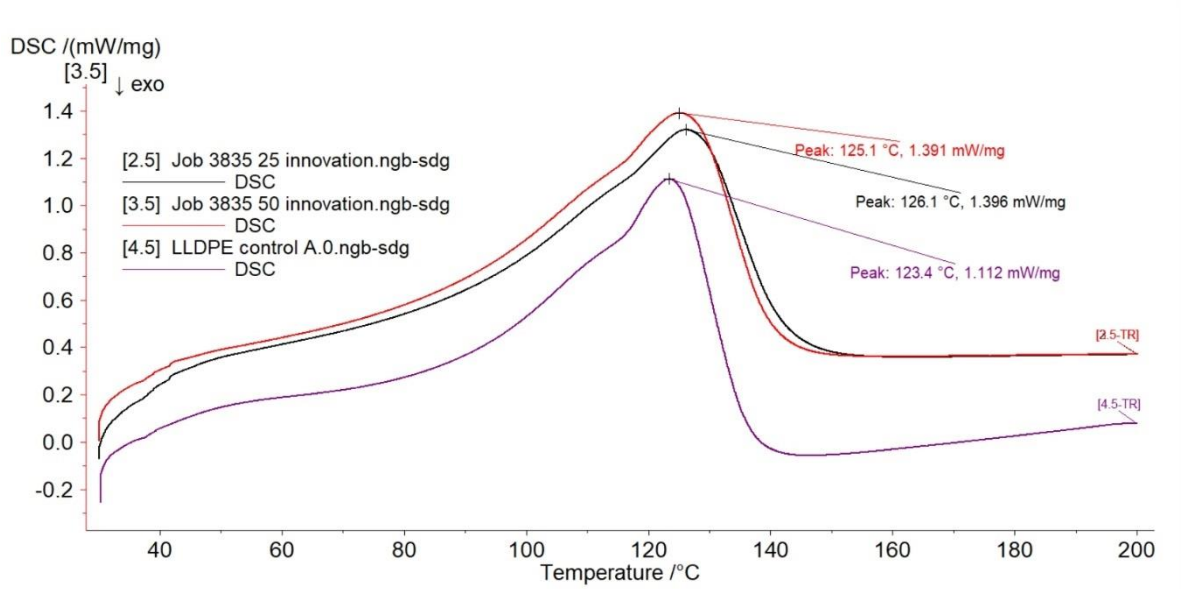


Figure 18. DSC Thermograms of the PLM-P-005, PLM-P-006 and PLM-P-007

Bulk Density

Bulk density tests were performed as per ISO 61:2000 and ASTM D1895-96, Test method C using plunger method. A 60 gram of sample was poured into the cylinder evenly. A plunger of mass 2300 grams was lowered into the cylinder and allowed to rest on the sample. After 1 min the height of the plunger was measured, and the bulk density of the material calculated.

Melt Flow Rate – MFR

The melt flow was undertaken on a UKAS calibrated machine in strict compliance with ISO 1133 The test conditions were:

- Temperature - 190 °C
- Load – 2.16 kg
- Cut-off – 60s

Approximately 4.5 g of polymer was packed into the heated barrel and loaded with a preheated piston and tested with both a 2.16 kg load. The polymer was then left for 5 minutes under load to equilibrate and remove air bubbles before conducting the test.

impact solutions
independent plastic experts

Worksheet	MFR Testing
Procedure Ref.	OP45 Appendix 1
Issue No.	2.0
Issue Date	February 2018

Job no:	3835	Operator:	GH	Date:	27/09/2019
	Stopwatch ref: 0808-3	Balance ref:	36020227		

delete as appropriate

Material ref:	MT / GM /0040	Machine no:	3		
Test load (kg)	2.16	Load wieght ID:	t198.3		
Test temp. (°C):	190	Machine temp. (°C):	190 *corrected*	Cut off interval (secs)	240

Cut off masses (g):	cut off 1	cut off 2	cut off 3
	0.0803	0.0837	0.0808

RESULT: 0.20 g/10min

Material ref:	MT / GM /4046 25% innnovation	Machine no:	3		
Test load (kg)	2.16	Load wieght ID:	t198.3		
Test temp. (°C):	190	Machine temp. (°C):	190 *corrected*	Cut off interval (secs)	60

Cut off masses (g):	cut off 1	cut off 2	cut off 3
	0.0746	0.0748	0.0753

RESULT: 0.75 g/10min

Material ref:	MT/GM/0040 2	Machine no:	3		
Test load (kg)	2.16	Load wieght ID:	t198.3		
Test temp. (°C):	190	Machine temp. (°C):	190 *corrected*	Cut off interval (secs)	240

Cut off masses (g):	cut off 1	cut off 2	cut off 3
	0.0782	0.0717	0.075

RESULT: 0.19 g/10min

Material ref:	MT/GM/4065 25% innovation repeat	Machine no:	3		
Test load (kg)	2.16	Load wieght ID:	t198.3		
Test temp. (°C):	190	Machine temp. (°C):	190 *corrected*	Cut off interval (secs)	60

Cut off masses (g):	cut off 1	cut off 2	cut off 3
	0.0765	0.0768	0.0764

RESULT: 0.77 g/10min

Material ref:	MT / GM /4046 50% innovation	Machine no:	3		
Test load (kg)	2.16	Load wieght ID:	t198.3		
Test temp. (°C):	190	Machine temp. (°C):	190 *corrected*	Cut off interval (secs)	60

Cut off masses (g):	cut off 1	cut off 2	cut off 3
	0.0827	0.0823	0.0823

RESULT: 0.82 g/10min

Material ref:	MT / GM /4046 50% innnovation repeat	Machine no:	3		
Test load (kg)	2.16	Load wieght ID:	t198.3		
Test temp. (°C):	190	Machine temp. (°C):	190 *corrected*	Cut off interval (secs)	60

Cut off masses (g):	cut off 1	cut off 2	cut off 3
	0.0825	0.0825	0.0825

RESULT: 0.83 g/10min

Figure 19. Melt Flow Rate results. The MT/GM/0040 material is used as Machine Control.

Appendix 2 - Blown film properties

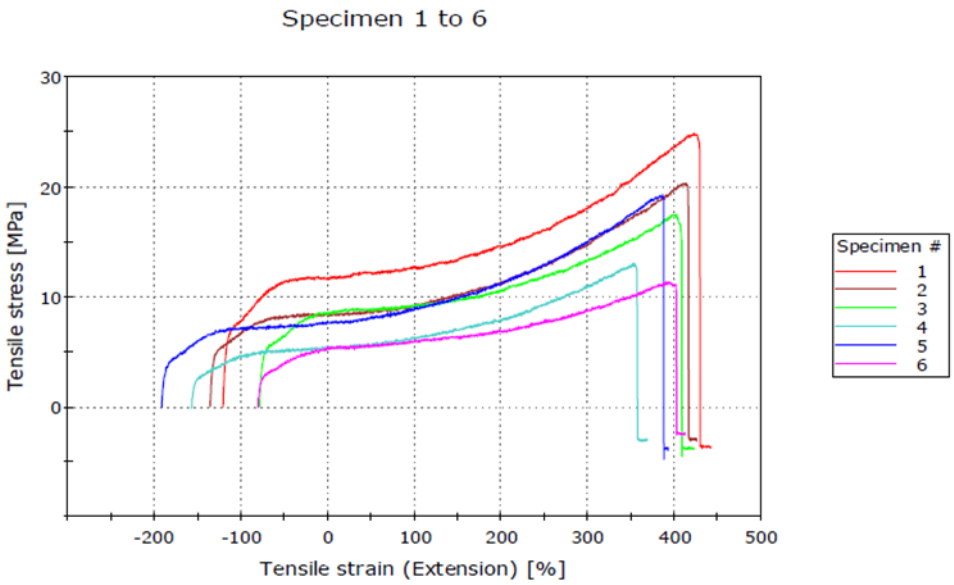
Tensile Tests

Tensile properties (strength and elongation at break) were determined in accordance with ISO 527-2 and ISO 527-3. Five specimens with rectangular 10mm width tensile coupons were cut out from the film rolls. The specimens were machined and left to condition at 23 °C for at least 20 hours before testing. Tests were carried in both machine and transverse direction of the films.

The tests were undertaken at 23 ± 0.5 °C on an Instron universal testing machine (model 3382) fitted with a 5kN load cell and a pair of tensile grips. A preload of 10 N was applied at 1 mm/min followed by a crosshead speed of 100 mm/min. The elongation at break and tensile strength were automatically determined from the Instron Software.

Job 3835 Polymateria B0 Control MD .is_tens

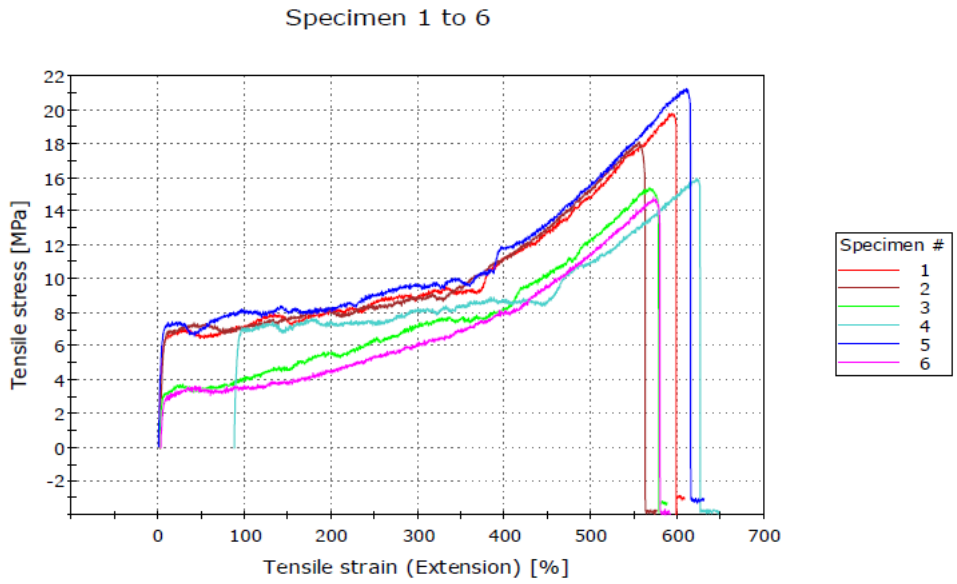
Graph 1



	Thickness [mm]	Width [mm]	Maximum Load [N]	Strength @ Yield [MPa]	Elongation @ Yield [%]	Strength @ Break [MPa]	Elongation @ Break [%]	Comments
1	0.02	10.00	6.23	24.9	> 422.2	24.9	422	
2	0.02	10.00	5.08	20.3	> 412.7	20.2	411	
3	0.02	10.00	4.38	17.5	> 400.6	17.5	402	
4	0.02	10.00	3.28	< 13.1	> 352.0	13.1	354	
5	0.02	10.00	4.83	-----	-----	19.2	382	
6	0.02	10.00	2.86	< 11.4	> 390.0	11.4	393	
Mean	0.02	10.00	4.44	17.5	395.5	17.7	394	
Standard deviation	0.0	0.0	1.2	5.5	27.2	5.0	24	

Figure 20. Tensile Test Results, Control Film, PLM-F-001 – MD

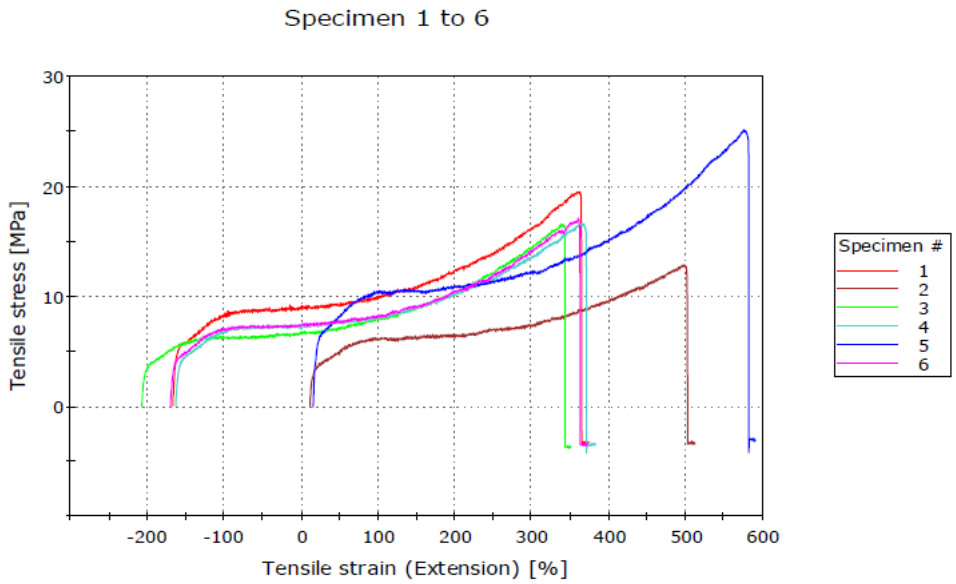
Graph 1



	Thickness [mm]	Width [mm]	Maximum Load [N]	Strength @ Yield [MPa]	Elongation @ Yield [%]	Strength @ Break [MPa]	Elongation @ Break [%]	Comments
1	0.02	10.00	4.95	< 7.0	> 28.8	19.8	592	
2	0.02	10.00	4.52	< 7.4	> 41.9	18.1	555	
3	0.02	10.00	3.85	< 3.8	> 28.8	15.4	567	
4	0.02	10.00	3.99	< 7.5	> 132.5	15.9	622	
5	0.02	10.00	5.32	< 7.5	23.4	21.2	609	
6	0.02	10.00	3.71	< 3.7	> 42.8	14.8	572	
Mean	0.02	10.00	4.39	6.1	49.7	17.5	586	
Standard deviation	0.0	0.0	0.6	1.9	41.3	2.6	26	

Figure 21. Tensile Test Results, Control Film, PLM-F-001 – TD

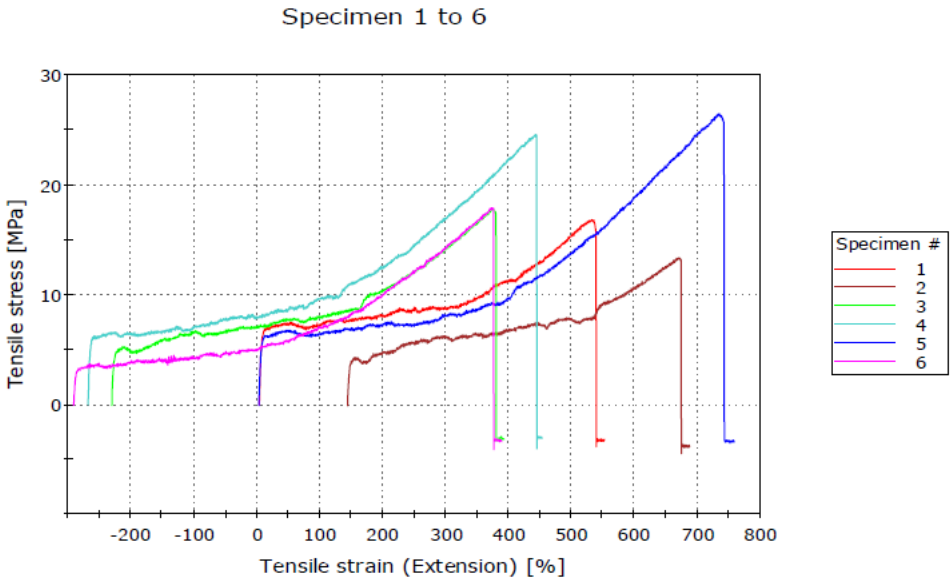
Graph 1



	Thickness [mm]	Width [mm]	Maximum Load [N]	Strength @ Yield [MPa]	Elongation @ Yield [%]	Strength @ Break [MPa]	Elongation @ Break [%]	Comments
1	0.02	10.00	4.88	19.5	> 361.8	19.5	362	
2	0.02	10.00	3.23	< 6.3	> 104.3	12.9	497	
3	0.02	10.00	4.15	16.6	> 337.8	16.6	339	
4	0.02	10.00	4.16	< 7.4	< -20.8	16.6	366	
5	0.02	10.00	6.30	< 10.7	> 133.9	25.1	576	
6	0.02	10.00	4.29	17.1	> 359.8	17.1	360	
Mean	0.02	10.00	4.50	13.0	212.8	18.0	417	
Standard deviation	0.0	0.0	1.0	5.5	162.5	4.1	97	

Figure 22. Tensile Test Results, - PLM-F-002- MD

Graph 1



	Thickness [mm]	Width [mm]	Maximum Load [N]	Strength @ Yield [MPa]	Elongation @ Yield [%]	Strength @ Break [MPa]	Elongation @ Break [%]	Comments
1	0.02	10.00	4.21	< 7.5	> 53.1	16.8	533	
2	0.02	10.00	3.35	< 6.6	> 346.9	13.3	672	
3	0.02	10.00	4.46	< 7.9	> 58.8	17.8	375	
4	0.02	10.00	6.15	< 6.7	< -223.7	24.6	444	
5	0.02	10.00	6.62	< 6.8	> 50.0	26.5	734	
6	0.02	10.00	4.48	< 4.8	< -68.2	17.9	372	
Mean	0.02	10.00	4.88	6.7	36.1	19.5	522	
Standard deviation	0.0	0.0	1.2	1.1	187.6	5.0	154	

Figure 23. Tensile Test Results, - PLM-F-002- TD

Sample text inputs: Client	
Sample number inputs: Material Reference - MT/GM	2675.
Sample number inputs: Calliper Reference	3348670.
Sample number inputs: Max. Conditioning Temp	23.00 C
Sample number inputs: Min. Conditioning Temp.	23.00 C
Sample number inputs: Test Temperature	23.50 C
Test: Test Speed	100.00 mm/min
Sample text inputs: Load Cell Reference	Instron 2525-173/78919
Sample text inputs: Machine Reference	Instron 3382

Graph 2

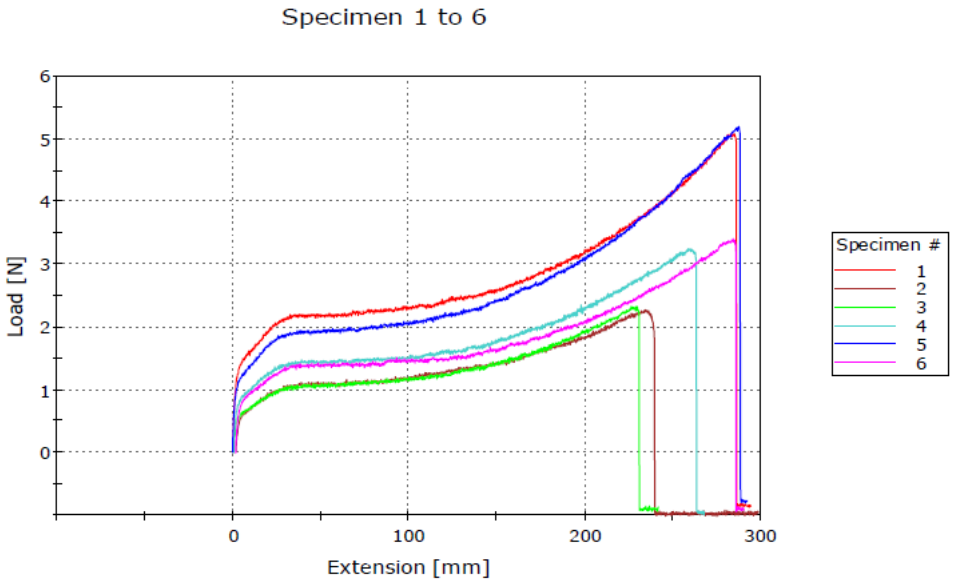
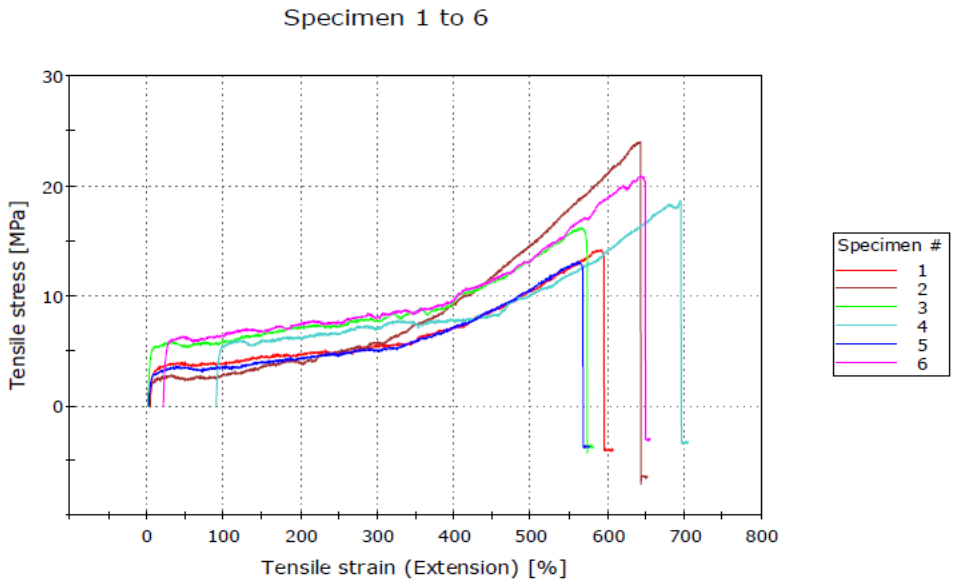


Figure 24. Tensile Test Results, - PLM-F-003-- MD

Graph 1



	Thickness [mm]	Width [mm]	Maximum Load [N]	Strength @ Yield [MPa]	Elongation @ Yield [%]	Strength @ Break [MPa]	Elongation @ Break [%]	Comments
1	0.02	10.00	3.56	< 4.1	> 49.8	14.2	592	
2	0.02	10.00	6.01	< 2.9	> 33.6	24.0	642	
3	0.02	10.00	4.06	< 5.9	> 33.2	16.3	565	
4	0.02	10.00	4.67	< 7.3	> 285.0	18.7	693	
5	0.02	10.00	3.31	< 3.7	> 37.4	13.2	560	
6	0.02	10.00	5.23	< 7.1	> 128.9	20.8	645	
Mean	0.02	10.00	4.48	5.2	94.7	17.9	616	
Standard deviation	0.0	0.0	1.0	1.9	100.2	4.1	52	

Figure 25. Tensile Test Results, - PLM-F-003— TD

Trouser – Tear Tests

Tear Tests properties (trouser test method) were determined in accordance with DIN EN ISO 6383 method. Five specimens with rectangular 10mm width tensile coupons were cut out from the film rolls. The specimens were machined and left to condition at 23 °C for at least 20 hours before testing. Tests were carried in both machine and transverse direction of the films.

The tests were undertaken at 23 ± 0.5 °C on an Instron universal testing machine (model 3382) fitted with a 5kN load cell and a pair of tensile grips. A preload of 10 N was applied at 1 mm/min followed by a crosshead speed of 250 mm/min. The elongation at break and tensile strength were automatically determined from the Instron Software.

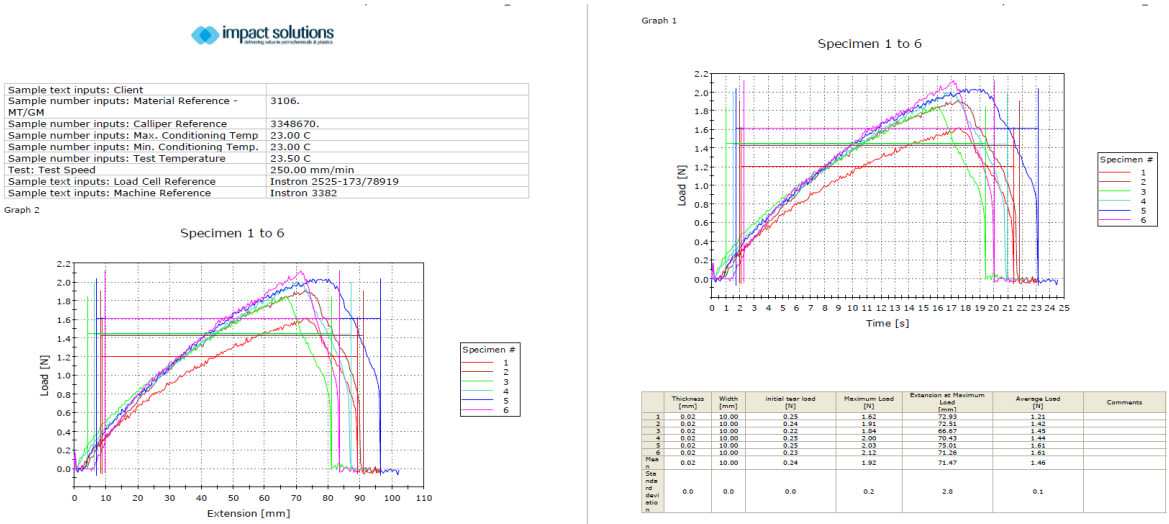


Figure 26. Tear Test Results, Control Film, PLM-F-001 – MD

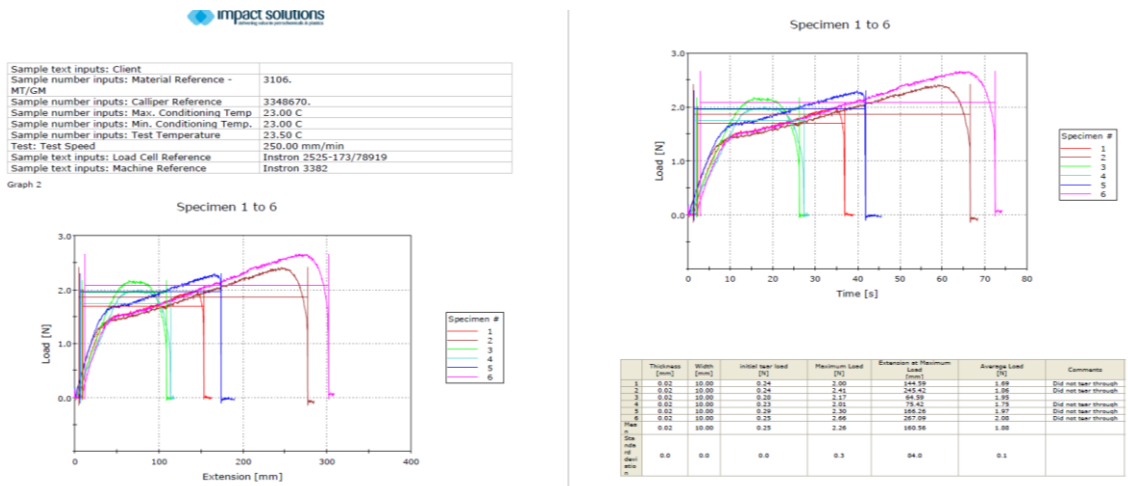


Figure 27. Tear Test Results, Control Film, PLM-F-001 – TD

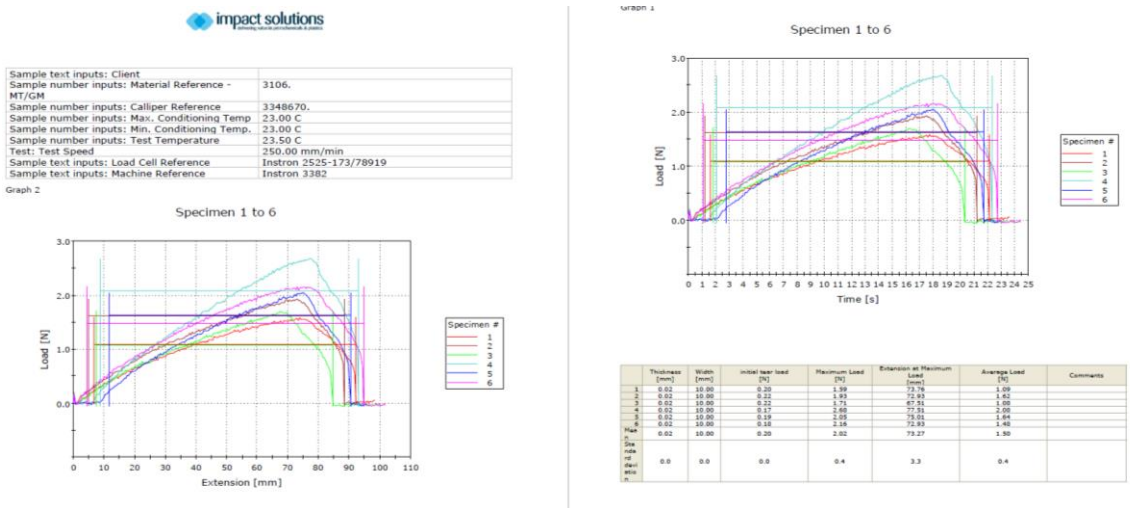
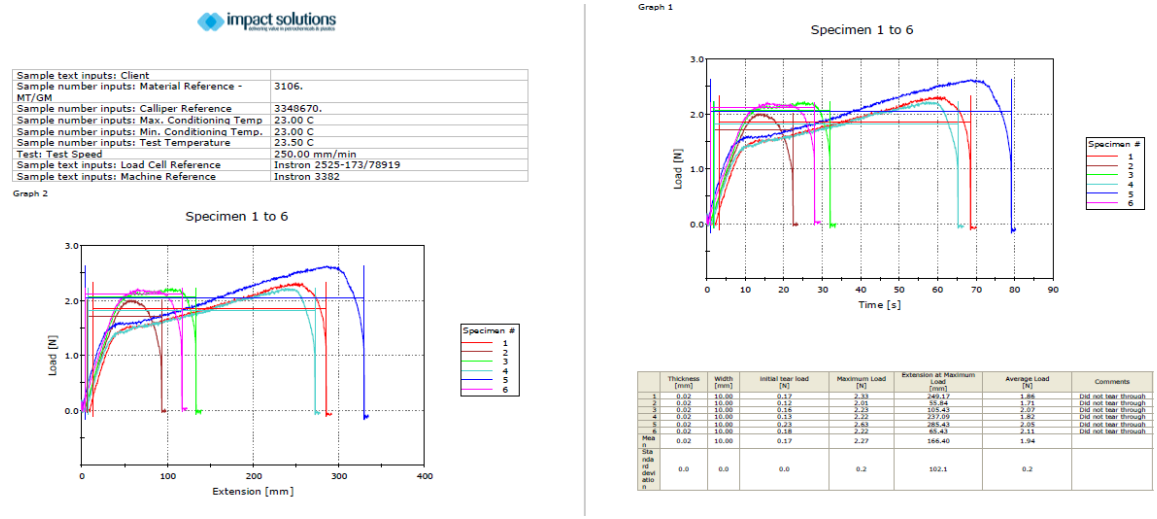


Figure 28. Tear Test Results, Control Film, PLM-F-002 – MD



Sample text inputs: Client	
Sample number inputs: Material Reference - MT/GM	3106.
Sample number inputs: Calliper Reference	3348670.
Sample number inputs: Max. Conditioning Temp	23.00 C
Sample number inputs: Min. Conditioning Temp.	23.00 C
Sample number inputs: Test Temperature	23.50 C
Test: Test Speed	250.00 mm/min
Sample text inputs: Load Cell Reference	Instron 2525-173/78919
Sample text inputs: Machine Reference	Instron 3382

Graph 2

Specimen 1 to 6

Load [N]

Extension [mm]

Specimen #

Graph 1

Specimen 1 to 6

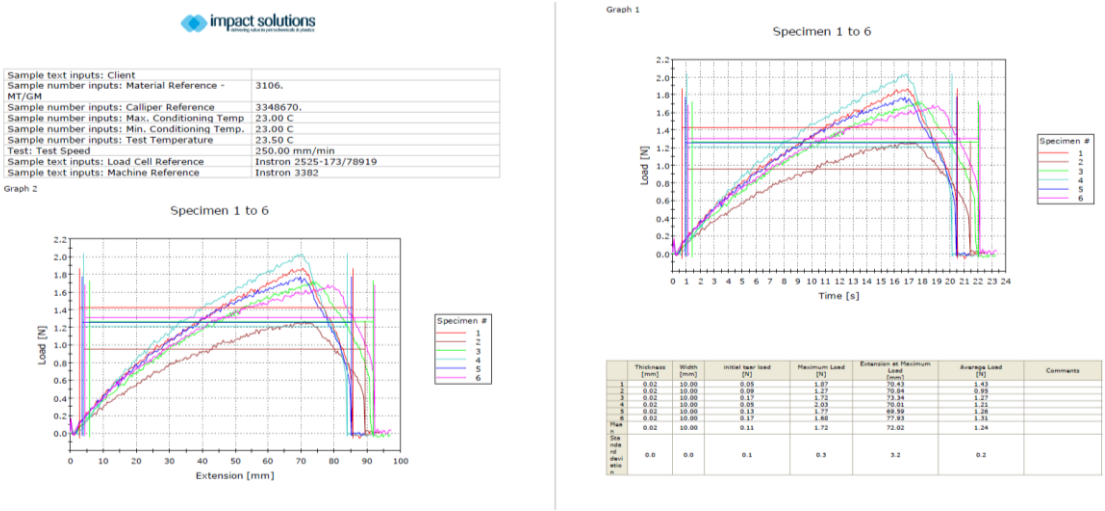
Load [N]

Time [s]

Specimen #

	Thickness [mm]	Width [mm]	Initial tear load [N]	Maximum Load [N]	Extension at Maximum Load [mm]	Average Load [N]	Comments
1	0.02	10.00	0.17	2.33	249.17	1.86	Did not tear through
2	0.02	10.00	0.12	2.01	55.84	1.71	Did not tear through
3	0.02	10.00	0.16	2.23	105.43	2.07	Did not tear through
4	0.02	10.00	0.13	2.22	237.09	1.82	Did not tear through
5	0.02	10.00	0.23	2.63	285.43	2.05	Did not tear through
6	0.02	10.00	0.18	2.22	65.43	2.11	Did not tear through
Mean	0.02	10.00	0.17	2.27	166.40	1.94	
Standard deviation	0.0	0.0	0.0	0.2	102.1	0.2	

Figure 29. Tear Test Results, Control Film, PLM-F-002 – TD



Sample text inputs: Client	
Sample number inputs: Material Reference - MT/GM	3106.
Sample number inputs: Calliper Reference	3348670.
Sample number inputs: Max. Conditioning Temp	23.00 C
Sample number inputs: Min. Conditioning Temp.	23.00 C
Sample number inputs: Test Temperature	23.50 C
Test: Test Speed	250.00 mm/min
Sample text inputs: Load Cell Reference	Instron 2525-173/78919
Sample text inputs: Machine Reference	Instron 3382

Graph 2

Specimen 1 to 6

Load [N]

Extension [mm]

Specimen #

Graph 1

Specimen 1 to 6

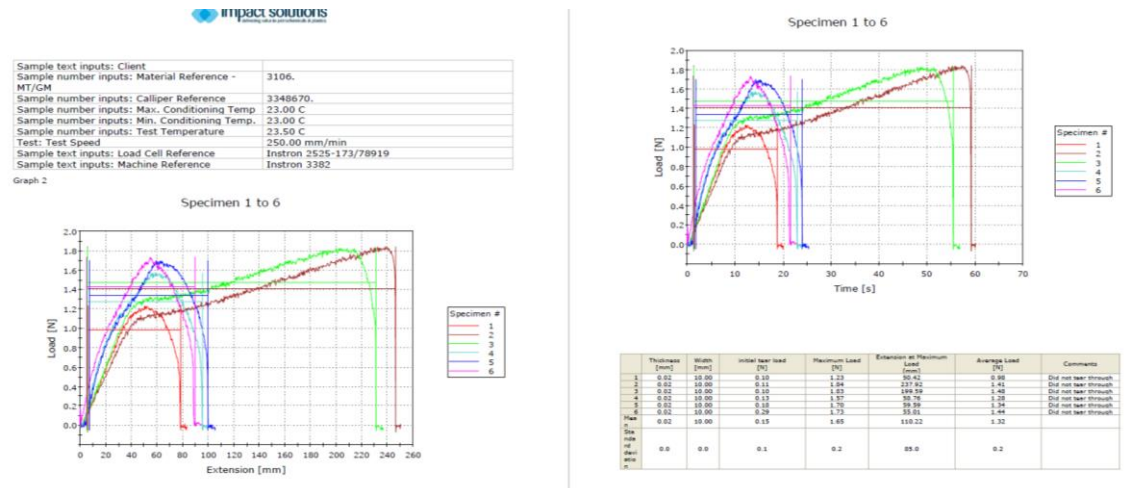
Load [N]

Time [s]

Specimen #

	Thickness [mm]	Width [mm]	Initial tear load [N]	Maximum Load [N]	Extension at Maximum Load [mm]	Average Load [N]	Comments
1	0.02	10.00	0.09	1.87	70.43	1.43	
2	0.02	10.00	0.09	1.27	70.84	0.93	
3	0.02	10.00	0.17	1.72	73.34	1.27	
4	0.02	10.00	0.05	2.03	70.01	1.21	
5	0.02	10.00	0.13	1.77	69.39	1.26	
6	0.02	10.00	0.17	1.88	77.93	1.31	
Mean	0.02	10.00	0.11	1.72	72.02	1.24	
Standard deviation	0.0	0.0	0.1	0.3	3.2	0.2	

Figure 30. Tear Test Results, Control Film, PLM-F-003 – MD



Sample text inputs: Client	
Sample number inputs: Material Reference - MT/GM	3106.
Sample number inputs: Calliper Reference	3348670.
Sample number inputs: Max. Conditioning Temp	23.00 C
Sample number inputs: Min. Conditioning Temp.	23.00 C
Sample number inputs: Test Temperature	23.50 C
Test: Test Speed	250.00 mm/min
Sample text inputs: Load Cell Reference	Instron 2525-173/78919
Sample text inputs: Machine Reference	Instron 3382

Graph 2

Specimen 1 to 6

Load [N]

Extension [mm]

Specimen #

Specimen 1 to 6

Load [N]

Time [s]

Specimen #

	Thickness [mm]	Width [mm]	Initial tear load [N]	Maximum Load [N]	Extension at Maximum Load [mm]	Average Load [N]	Comments
1	0.02	10.00	0.10	1.23	30.42	0.90	Did not tear through
2	0.02	10.00	0.11	1.84	237.92	1.41	Did not tear through
3	0.02	10.00	0.10	1.83	199.59	1.48	Did not tear through
4	0.02	10.00	0.13	1.57	98.78	1.28	Did not tear through
5	0.02	10.00	0.18	1.70	99.99	1.34	Did not tear through
6	0.02	10.00	0.29	1.73	55.01	1.44	Did not tear through
Mean	0.02	10.00	0.15	1.65	110.22	1.32	
Standard deviation	0.0	0.0	0.1	0.2	85.0	0.2	

Figure 31. Tear Test Results, Control Film, PLM-F-003 – TD

Dart Impact

BS EN ISO7765-1 (2004) Determination of the impact resistance by the free falling dart impact – Part 1 Stair Case Methods

The test was undertaken using Method A which employs a 38 mm ± 1 mm diameter hemispherical head dropped from a height of 0.66 ± 0.01 m. The stair case method requires the mass of the dart to be decreased or increased by uniform increments (20 g was used in this work) depending on the result failure or no failure observed for the specimen.

The test arrangement is shown in Figure 32. A film is placed under the dart and a vacuum switched on to pull the test area taught. A clamp is then placed over the film to hold it in place and prevent slippage. The dart, with appropriate weights, is held and released from an electromagnet.

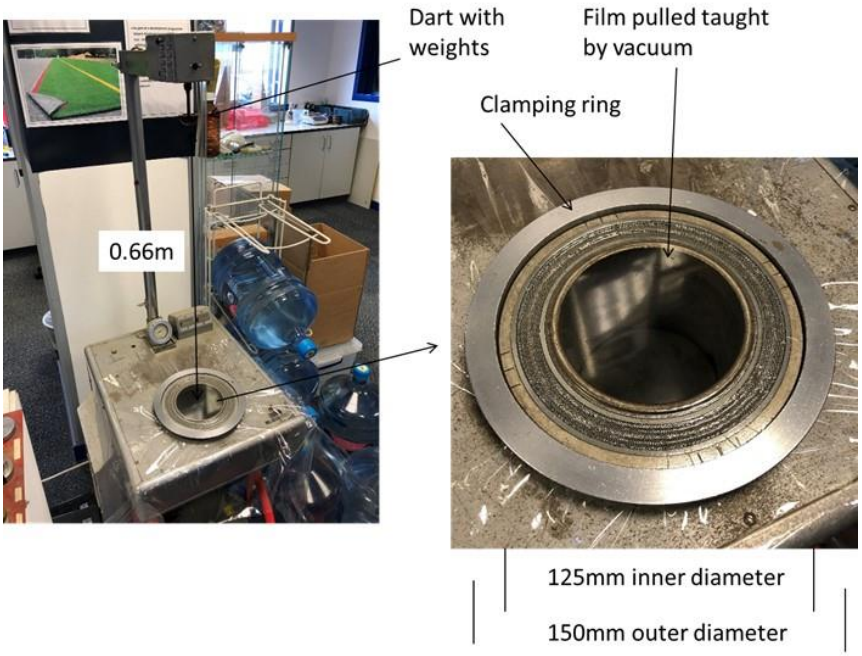


Figure 32. Dart Impact Apparatus

Haze Measurements

The Haze analysis was carried out following the general principles of the DIN EN ISO 13468 and the ASTM D1003. A haze/transmission unit from DRICK instruments was used for the analysis. The chosen Illuminant was the "C".

ASTM D1003	illuminant C	
PLM-F-001	Haze %	Transparency %
1	10.51	91.27
2	9.38	91.61
3	10.7	90.93
4	7.89	91.8
5	9.7	91.78
average	9.6	91.5
std. dev.	1.1	0.4
PLM-F-002	Haze %	Transparency %
1	6.28	91.56
2	7.41	91.66
3	8.08	92.52
4	7.86	92.74
5	8.36	92.81
average	7.6	92.3
std. dev.	0.8	0.6
PLM-F-003	Haze %	Transparency %
1	9.73	92.8
2	11.05	92.84
3	10.67	92.94
4	9.41	92.94
5	10.89	91.76
average	10.4	92.7
std. dev.	0.7	0.5

Figure 33. Haze Results