

Date: 2 September 2024

Report: 18703/002

Test Report:

- **Compositional Analysis:**

- Structural Determination: Identification of Polymer Type
- Elemental Content: Determination of Prodegradant Catalysts

- **Accelerated Ageing Studies:**

- Polymer Oxidation During Accelerated Ageing:
 - Thermal Stability
 - Thermal Degradation, Following Initial UV Exposure

Test Reference: 18703 Polietilenos Impresos Polim

Product Tested: HDPE T-Shirt Bag

Prepared for: Polietilenos Impresos Polim

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TEST REPORT

1.0 AIMS

- To determine the polymer composition of the HDPE T-Shirt Bag sample by infrared (IR) spectroscopy.
- To evaluate the presence of prodegradant catalysts in the HDPE T-Shirt Bag sample by determination of the prodegradant catalyst metal cations by X-ray fluorescence (XRF) spectroscopy.
- To evaluate the stability and degradation behaviour of the HDPE T-Shirt Bag sample by means of accelerated laboratory ageing techniques, while monitoring extent of polymer oxidation by infrared (IR) spectroscopy as a function of time.

2.0 SAMPLE DETAILS

Samples Provided by: Polietilenos Impresos Polim

Product Type: HDPE T-Shirt Bag

Date Received: 31/07/2024

Table 1: Sample Details

SEPTL Sample ID	Client Reference	Polymer Type	Prodegradant Additive
18703/9121	A018	HDPE	1% d ₂ w 93224/I

Table 1 is based solely on information provided by the client.

3.0 RESULTS & CONCLUSIONS

3.1 Compositional Analysis

3.1.1 Determination of Polymer Composition

The sample polymer type is determined by infrared (IR) spectroscopy. The infrared spectrum of sample 18703/9121 (Figure 1) demonstrates features corresponding to polyethylene (Table 2).

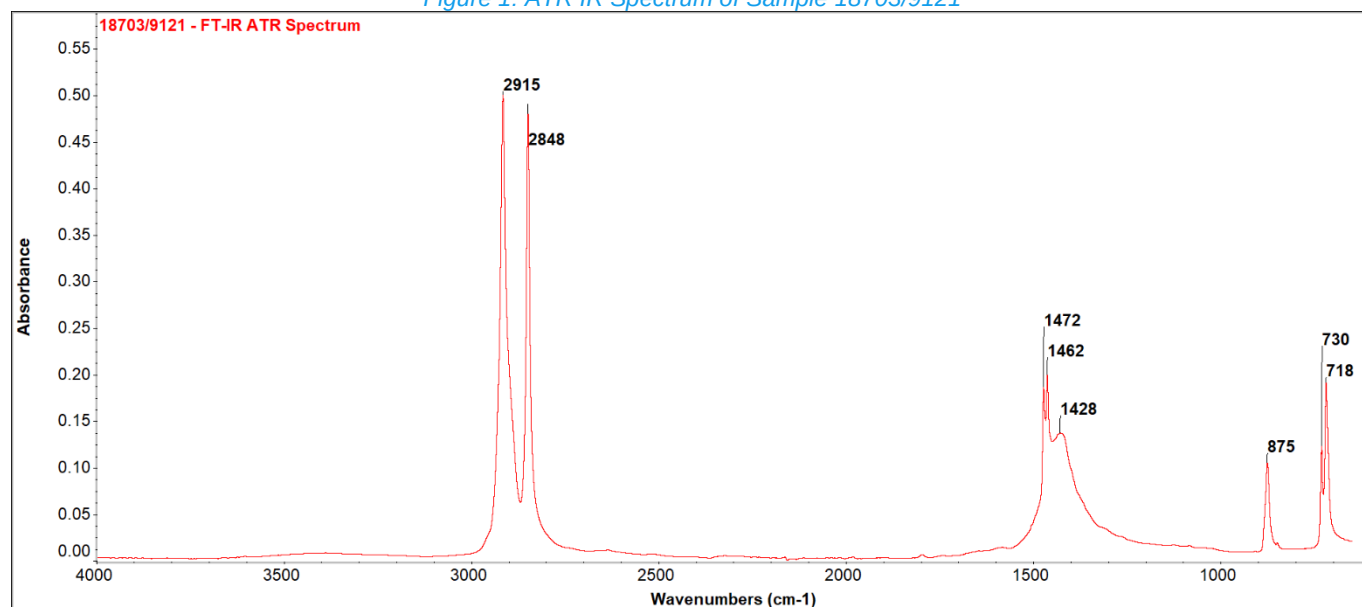
Peak splitting of features corresponding to CH₂ vibrations suggest a semi-crystalline character, i.e., HDPE or LLDPE.

There is no evidence of polymer oxidation in sample 18703/9121, as received.

Table 2: Determination of Polymer Type

Sample ID	Absorption Bands	Intensity/Shape	Bond Assignment		Polymer/Compound
18703/9121	2915 cm ⁻¹	strong, sharp	CH ₂ asymmetric C-H stretch		Polyethylene $\left[\text{CH}_2\text{—CH}_2 \right]_n$
	2848 cm ⁻¹	strong, sharp	CH ₂ symmetric C-H stretch		
	1472 cm ⁻¹	medium, sharp; doublet	CH ₂ bend	crystalline	
	1462 cm ⁻¹			amorphous	
	730 cm ⁻¹	medium, sharp; doublet	CH ₂ rock	crystalline	
	718 cm ⁻¹			amorphous	
	1428 cm ⁻¹	strong, broad	Carbonate, CO ₃ stretch		Calcium carbonate $\left[\text{Ca}^{2+} \right] \left[\begin{array}{c} \text{O} \\ \vdots \\ \text{O}=\text{C}=\text{O} \\ \vdots \\ \text{O} \end{array} \right]^{2-}$
	875 cm ⁻¹	weak, sharp			

Figure 1: ATR IR Spectrum of Sample 18703/9121



3.1.2 Determination of Prodegradant Catalysts

The presence of prodegradant catalysts in each sample is confirmed by determination of the prodegradant catalyst metal cations by energy-dispersive X-ray fluorescence (XRF) spectroscopy.

The prodegradant catalyst content result, as determined by X-ray fluorescence (XRF) spectroscopy, is given in Table 3.

Table 3: Determination of Prodegradant Catalyst

Sample ID	Spectrum Ref.	Prodegradant Content
18703/9121	212014/2920	Prodegradant Present, Effective Concentration

3.2 Accelerated Ageing

3.2.1 Thermal Stability

The real-time stability of polymer products stored at ambient temperatures and protected from extended exposure to sunlight is evaluated over shorter period of time in the laboratory by monitoring stability and degradation during thermal ageing at elevated temperatures according to ASTM D5510.

Polymer stability and degradation is evaluated by determination of polymer oxidation by infrared spectroscopy in accordance with ISO 10640. The increase in magnitude of features of the infra-red spectra corresponding to the carbonyl products of polymer oxidation, is recorded as carbonyl optical density. The period of accelerated thermal ageing where no significant increase in carbonyl optical density (Table 6) is observed is considered to be representative of the real-time period of product stability in storage conditions.

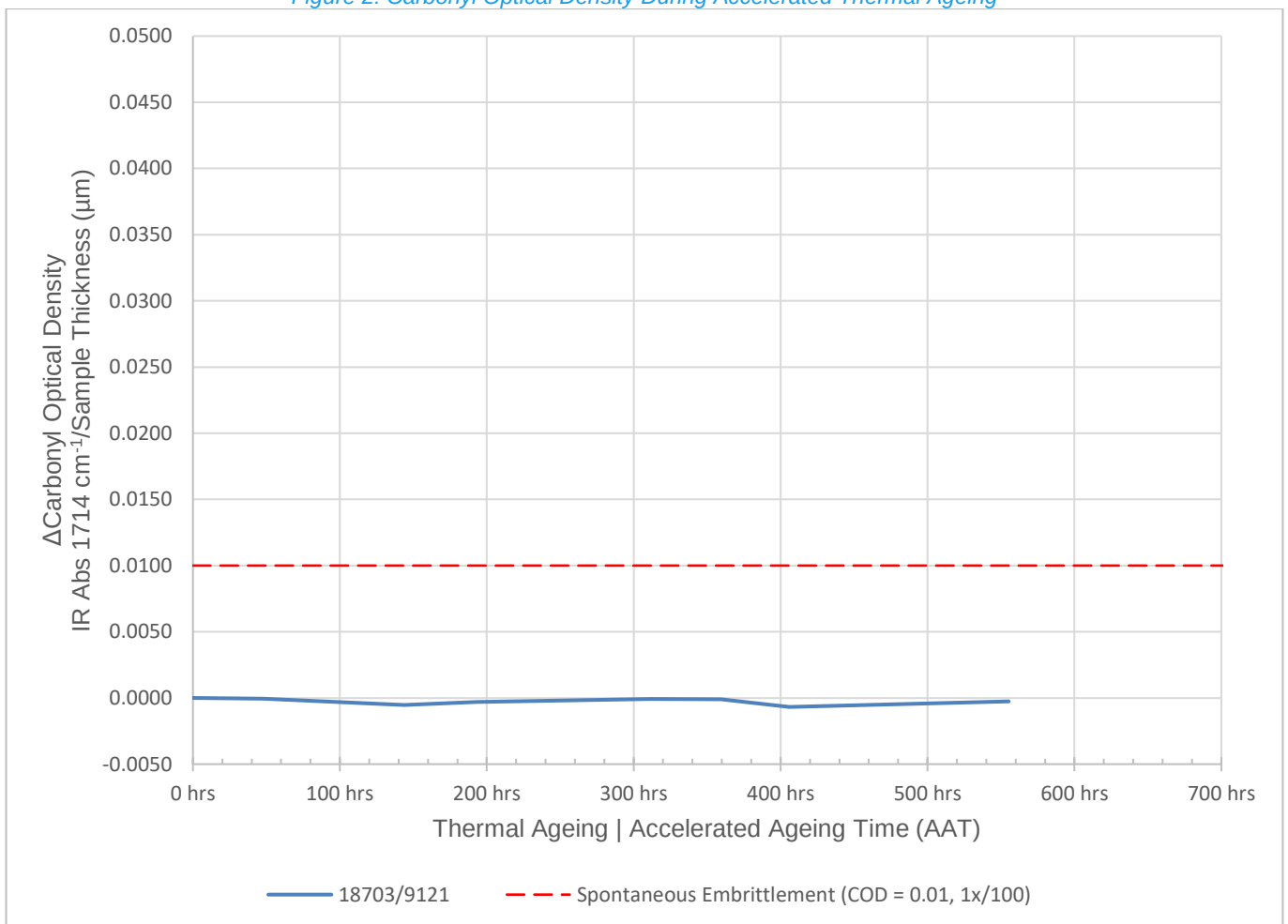
Sample 18703/9121 demonstrated no significant oxidation during the accelerated stability test (Table 4/Figure 2). This result is consistent with the sample having undergone no significant degradation.

The absence of degradation in the sample for the duration of this test confirms that the product is stable in dark conditions, at ambient temperatures for an initial life period corresponding to the product life. Based on these results a product life of 12 months is recommended for this product, provided storage at an average ambient temperature which does not exceed 30°C in indoor storage conditions and is protected from extended sunlight exposure.

Table 4: Carbonyl Optical Density During Accelerated Thermal Ageing

Accelerated Ageing Time (AAT)	Δ Carbonyl Optical Density (IR Abs 1714 cm ⁻¹ /Thickness)
	18703/9121
0 hrs	0.0000
48 hrs	-0.0001
144 hrs	-0.0005
193 hrs	-0.0003
311 hrs	-0.0001
359 hrs	-0.0001
406 hrs	-0.0007
555 hrs	-0.0003

Figure 2: Carbonyl Optical Density During Accelerated Thermal Ageing



3.2.2 Thermal Degradation, Following Initial UV Exposure

Polymer degradation in dark conditions, following initial exposure to sunlight is evaluated in a shorter period of time in the laboratory by monitoring degradation during accelerated fluorescent UV ageing in accordance with ASTM D5208 followed by thermal ageing at elevated temperatures according to ASTM D5510.

Polymer degradation is evaluated by determination of polymer oxidation by infrared spectroscopy in accordance with ISO 10640. The increase in magnitude of features of the infra-red spectra corresponding to the carbonyl products of polymer oxidation, is recorded as carbonyl optical density. An increase in carbonyl optical density of 0.0100 corresponds to a >95% reduction in mechanical properties and is therefore considered indicative of advanced degradation as such to bring about spontaneous embrittlement (Table 6). The rate of degradation is evaluated and compared by monitoring carbonyl optical density as a function of ageing time.

3.2.2.1 48 hours Initial UV Exposure

The sample was initially exposed to constant fluorescent UV ageing for a period of 48 hours. The sample was then exposed to accelerated thermal ageing in dark conditions.

Sample 18703/9121 demonstrated a significant increase in carbonyl optical density (Table 5/Figure 3). This result is consistent with this sample having undergone significant degradation.

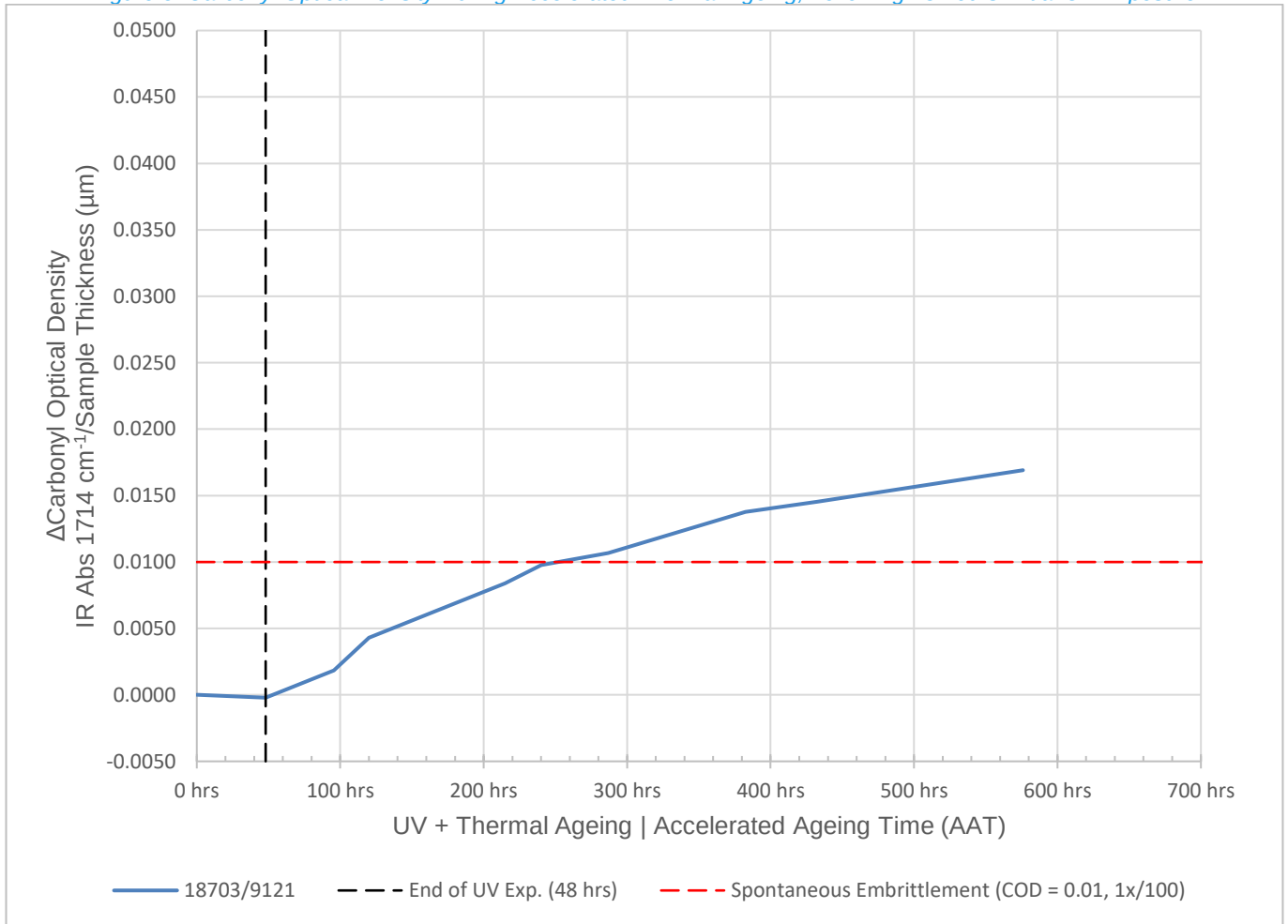
A carbonyl optical density value of ≥ 0.0100 is consistent with oxidation and molecular weight reduction of the polymer film sufficient to bring about a substantial reduction in mechanical properties (Table 6), this together with an observation of spontaneous embrittlement of the sample is sufficient to confirm an absolute elongation at break of 5% or less, according to ASTM D3826.

The observation of degradation in the sample which contains the prodegradant additive is consistent with the prodegradant catalyst promoting degradation of the product in dark conditions, following initial exposure to sunlight in the environment as litter.

Table 5: Carbonyl Optical Density During Accelerated Thermal Ageing, Following 48 hours Initial UV Exposure

Accelerated Ageing Time (AAT)	Exposure	Δ Carbonyl Optical Density (IR Abs 1714 cm ⁻¹ /Thickness)
		18703/9121
0 hrs	UV	0.0000
48 hrs		-0.0002
96 hrs	Thermal	0.0018
120 hrs		0.0043
215 hrs		0.0084
240 hrs		0.0098
287 hrs		0.0107
383 hrs		0.0138
433 hrs		0.0145
576 hrs		0.0169

Figure 3: Carbonyl Optical Density During Accelerated Thermal Ageing, Following 48 hours Initial UV Exposure



4.0 TEST METHODOLOGY

4.1 FT-IR Spectroscopy

4.1.1 Structural Determination: Identification of Polymer Type

For characterisation of polymer composition, the infrared (IR) spectra are recorded by attenuated total reflection (ATR), in accordance with ISO 10640 using a Thermo Scientific Nicolet iS10 Fourier transform infrared (FT-IR) spectrometer fitted with a smart iTR accessory and diamond ATR crystal. Spectra are collected across the range of 650 to 4,000 cm^{-1} , ≥ 16 scans, with a resolution of 4 cm^{-1} .

4.1.2 Polymer Oxidation

For determination of polymer oxidation, the infrared (IR) spectra are recorded by transmission, in accordance with ISO 10640 using a Thermo Scientific Nicolet iS10 Fourier transform infrared (FT-IR) Spectrometer fitted with a transmission accessory. Spectra are collected across the range 650 to 4,000 cm^{-1} , ≥ 16 scans, with a resolution of 4 cm^{-1} .

4.1.2.1 Carbonyl Optical Density Calculation

The extent of oxidation is reported as the carbonyl optical density, a function of the net increase in infrared carbonyl (C=O) absorbance at 1714 cm^{-1} during ageing, per unit of the path length (sample thickness in μm):

$$\text{Equation 1: Carbonyl Optical Density} = \frac{IR\ Abs_{1714\ \text{cm}^{-1}}}{\text{Thickness}\ (\mu\text{m})}$$

4.1.2.1.1 Extent of Oxidation, Interpretation of Carbonyl Optical Density

The carbonyl optical density value may be interpreted to indicate the approximate extent of degradation of polyolefin films, according to Table 6.

Table 6: Carbonyl Optical Density, Indicated Extent of Degradation

Carbonyl Optical Density	Extent of Degradation
0.000	No significant degradation
0.001	~50% reduction in mechanical properties (EaB)
0.010	Spontaneous Embrittlement, ~>95% reduction in mechanical properties (EaB)
≥ 0.030	Significant Biodegradability

4.2 XRF Spectroscopy

The XRF spectrum of each unaged sample is recorded using a Bruker S2 Puma Series 2 benchtop spectrometer in air over 120 s live time, using an Ag X-ray anode and graphene window detector, with a 40.00 kV voltage, automatic current settings (300 kcps), and a 500.0 µm aluminium filter. Film samples were prepared in 38 mm diameter HDPE XRF sample cups and the total thickness made up to ~200 µm with 36 mm discs cut from the bulk material using a James Heal 230/10 sample cutter.

4.2.1 Determination of Prodegradant Catalyst

The concentration of prodegradant catalyst metal cations is quantified by correlation with a calibration of validated reference samples.

4.3 Accelerated Ageing Exposure

4.3.1 Sample Preparation/Holders

35 x 90 mm film samples were cut using a scalpel and secured in a sample holder with four exposure windows.

4.3.2 Thickness Determination

The thickness of the sample material is determined before ageing using a digital electronic micrometer, in not less than four random locations across the test sample and the average value recorded.

4.3.3 Accelerated Thermal Ageing

Thermal ageing of the samples was carried out in a Memmert UFE 600 fan assisted oven at a temperature of 70°C in accordance with ASTM D5510 Procedure B: Forced Ventilation Oven.

4.3.3.1 Thermal Stability Real Time Exposure Prediction

The real-time period (RT) at ambient temperature (T_{RT}) represented by accelerated ageing time (AAT) at elevated accelerated ageing temperature (T_{AA}) is predicted in accordance with ASTM F1980 using the relationship outlined in Equation 2.

The calculation is performed using an anticipated average storage exposure temperature (T_{RT}) of 30°C and a conservative ageing factor (Q_{10}) of 2.

$$\text{Equation 2: } AAT = \frac{RT}{Q_{10}^{[(T_{AA}-T_{RT})/10]}}$$

4.3.4 Accelerated Fluorescent UV Ageing

Samples were exposed to ultraviolet radiation in accordance with ASTM D5208 in a Q Panel QUV/se test apparatus fitted with UVA 340 lamps, set to a black panel temperature of 50°C and irradiance of 0.78 W/m²/nm @ 340 nm.

5.0 REPORT HISTORY

Date	Report Ref.	Author	Comments
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Previous Version

08/08/2024	18703/001	YB	Compositional analysis report
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Current Version – this report supersedes all previous versions

02/09/2024	18703/002	YB	Added accelerated ageing data
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6.0 REPORT AUTHORISATION

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The information presented in this report is based on the material tested. Performance of finished products depends on their formulation, the conditions under which, and length of time for which the additives and finished product is stored, and on the method of manufacture of the finished product, and the heat, light, stress, and other conditions to which the finished product is exposed. Nothing in this report constitutes or implies a license to use Symphony's intellectual property.

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