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RECYCLING REPORT ON D2W OXO-BIODEGRADABLE PLASTICS

Roediger Agencies is an analytical laboratory, specialising in troubleshooting and research of polymers and chemical and physical testing of polymers. The company is owned and managed by Dr. Andy Roediger (Ph.D., Chem.), a polymer scientist experienced in polymeric applications.

Situated in the buildings of the Institute for Polymer Science at the University of Stellenbosch, we are in touch with ground breaking polymer research and technology. We have access to a wide range of advanced analytical, thermal, and mechanical equipment. This allows extensive and complete investigation of problematic or research materials, and enables us to blend practical and technical knowledge with relevant data.

Tests were carried out by the analytical laboratory of Roediger Agencies cc to study the effect of adding a pelletised primary test film blown from virgin LDPE polymer (Sasol LT019) and containing 1% by mass of d2w pro-degradant additive (Grade 93389/W), to pellets made from a conventional LDPE printed polyethylene film without d2w. The performance of this secondary test film made with the mixed pellets was then measured.

Tests in Part 1 of this report were carried out without added stabilisers, and in Part 2 with stabilisers added to the secondary test film.

EXECUTIVE SUMMARY

Recycling of factory-off cuts and plastic waste whose provenance is known is useful, but post-consumer waste film is often contaminated, and can consist of several different types of polymer. Nevertheless if mechanical recycling of post-consumer waste is desired, we confirm from the tests reported below and from our own experience, the following statements by the Oxo-biodegradable Plastics Association.

"Recycled plastics can, like ordinary plastics, accumulate for decades before completely degrading if they get into the open environment. However, recycled plastic and ordinary plastic can now be made oxo-biodegradable by the inclusion of a pro-degradant formulation at the extrusion stage. This significantly accelerates the rate of degradation, and therefore of bio-degradation in a primary product with pro-degradant

included at the rate recommended by the additive supplier – usually at least 1%. However, if that primary product is recycled with normal polymer the effect of the additive is attenuated.

The length of the useful life of an oxo-biodegradable plastic product is determined by the type of resin used, the type and concentration of catalyst and the stabilisation package in the additive formulation, which can be modified so that the product degrades according to whatever approximate timescale is required.

Short life products

If the new product to be made from recyclate which contains a pro-degradant formulation is intended for short-life uses such as garbage-sacks, bin-liners, shopping bags, bread wrappers etc. the effect of any pro-degradant formulation is unlikely to manifest itself before the end of the intended service-life. Biodegradability for such items is in any event desirable, because a proportion of them will find their way into the land or sea environments, where they could otherwise subsist for decades after being discarded.

Long life products

Since polymers lose stabilisation each time they are reprocessed, it is good practice when making long-life products to add new stabilisers, whether the feedstock contains oxo-biodegradable plastic or not. If suitably formulated, the stabilisers will also neutralise any pro-oxidant which may be present. The recycler does not often determine the final destination of the recyclate. It could go into various products, damp proof membrane, solid articles, refuse sacks etc. and at varying inclusion rates. Stabilisers would be added by the next processor in the chain - the manufacturer of the finished recycled-content product.

(a) Building Films

If the new product to be made is a plastic film intended for long-term durability - such as a building film for damp-proofing or waterproofing, the presence of oxo-biodegradable additive is irrelevant if the film is buried with no access to oxygen. This is because the process of oxo-degradation cannot proceed in the absence of oxygen.

Further, the specification in some countries for these films requires the use of a virgin polyolefin, and recyclate is not therefore used. For other building films the specification will usually require stabilisers. There will of course be no pro-degradant formulation in recyclate made from conventional in-house scrap or scrap whose provenance is known.

In the case of lower-grade building films, where no guarantee is given, these are often made from recyclate whose origin is not known, and the manufacturer should always add stabilisers, whether the feedstock contains a pro-degradant formulation or not.

(b) Pipes

According to South African Standards piping is manufactured to a specification which permits the use of recyclate only from "in-house scrap." Small bore piping class 6 and 10 is usually LDPE and, larger sizes,

HDPE. "In-house scrap" is scrap which has been generated during manufacture of the SABS grade pipe which can be chipped up and added back.

There is therefore no difficulty with the manufacture of such piping, as the content of the recyclate is known.

(c) Thick cross-section products for extrusion and injection moulding

It is our opinion that up to 25% d2w-containing recyclate can be incorporated into extrusions or mouldings that have a thickness >1 mm without having any detrimental effect on outdoor exposure. The main reason for this is that the amount of active pro-degradant is so small in concentration that the degradation mechanism would be at the same rate as any recycled polyethylene without d2w. In other words it is suitable to be used for items such as buckets, road cones, garden furniture, or any other thicker-walled article.

Difference of results with and without stabilisation

In the case of thin film incorporating percentages of d2w-containing film up to a maximum of 50%, the reduction of tensile strength and elongation with exposure to accelerated UV ageing (and the heat associated with it) was negligible. In most cases it was found that the pure recycled waste LDPE degraded faster in UV light without the addition of d2w waste film.

In the case of heat-ageing it was found that for a period of 200 hours at 60 °C, little or no change in physical properties was observed. After heat-ageing for 400 hours at 60 °C, a larger decrease in physical properties was found in the formulations containing higher percentages of d2w waste film, than without.

Thus, exposure to UV light has no detrimental effect, nor does a 200 hour exposure to elevated temperature in the dark, but longer exposure to elevated temperature shows greater reduction in physical properties in samples that have higher percentages of pelletised d2w film. 200 hours at 60°C is equivalent to 3 months in storage without exposure to UV light at an average storage temperature of 25°C, and 400 hours in same conditions is equivalent to 6 months storage.

With base-stabiliser added, after 24 months of sun in South Africa there is no evidence that the addition to recycled polyethylene of up to 25% regrind containing d2w, makes any difference to the storage life or outdoor life expectancy of the film.

All samples will be kept for one year and discarded afterwards.

CONCLUSION

We are therefore able to confirm that plastic products made with Symphony's d2w oxo-biodegradable technology may be recycled without any significant detriment to the newly formed recycled product.

THE TESTS

PART 1 - WITHOUT ADDED STABILISER

Method

A quantity of virgin LDPE polymer (Sasol LT019) was extruded with 1% (by mass) of d2w pro-degradant additive, and blown into film, which was then pelletised. The pelletised d2w-containing film was blended in ratios of 0, 10, 20, 35, and 50% with 300kg of purchased pelletised printed LDPE waste film. Secondary test-film of approximately 40 microns (0.04mm) was blown from each sample.

Films of the following constituents were blown:

- As a control - 100% Waste LDPE repelletised printed film, referred to as "100:0";
- 90% Waste LDPE repelletised printed film +10% d2w film repelletised, referred to as "90:10";
- 80% Waste LDPE repelletised printed film +20% d2w film repelletised, referred to as "80:20";
- 65% Waste LDPE repelletised printed film +35% d2w film repelletised, referred to as "65:35";
- 50% Waste LDPE repelletised printed film +50% d2w film repelletised, referred to as "50:50";

The secondary test-films were exposed to accelerated weathering by UV exposure, equivalent to a period of 2 years in South African conditions. Samples were removed at the following time intervals: 0.26, 0.66, 1.33, and 2 simulated years of exposure. A further five secondary test films were exposed to accelerated thermal ageing in an aerated oven, in the dark at 60 degrees centigrade. Samples were removed at 100, 200 300 and 400 hours. All samples removed were tested for tensile strength/elongation at break and carbonyl index.

FLUORESCENT UV AGEING

The tests were carried out in general accordance with ASTM D5208*: Standard Practice for Fluorescent Ultraviolet (UV) Exposure of photodegradable plastic.* Samples were exposed to ultraviolet radiation in a Q Panel QUV/se test apparatus (or equivalent). A black panel temperature of 50°C was used in conjunction with a humid environment. The irradiance of the lamps is 0.78W/m^2. Film specimens were withdrawn at time points corresponding to 100, 250, 500, and 750 hours for tensile testing and carbonyl index. An unexposed sample was kept as a control.

A QUV fluorescent UV/condensation tester was used to accelerate weathering. UVB radiation is responsible for most polymer damage.

The bulbs used were of the type UVB–313, which gives the highest irradiation at a wavelength of 313 nm. Results obtained with these lamps correlate well with results of outdoor exposure for gloss retention on coatings and for the material integrity of plastics. With the exception of the automotive industry, the UVB-313 is the most widely used light source for ASTM G-53 devices.

Two types of weathering cycles were used; 1) Wet cycle is an 8 hour exposure to a UV cycle at 45 °C, followed by a 4 hour condensation cycle at 50 °C, only the actual UV exposure hours are taken into consideration to determine the outdoor exposure equivalent. 2) Dry cycle is a continuous exposure to a UV cycle at 45 °C.

The reported number of hours of exposure is equivalent to the total time of UV exposure recorded. In our experience, an exposure time of 3000 hours correlates to a ten-year period in South Africa. It must be borne in mind that the degradation that takes place is not linear over the time of exposure, it is exponential. A table of exposure hours in the QUV versus outdoor exposure in South Africa has been established and is shown below.

Years outdoor equivalent in South Africa	QUV exposure (Hours)
1	400
2	750
3	1033
4	1316
5	1600
6	1880
7	2160
8	2440
9	2720
10	3000

Table 1: Estimated correlation between outdoor weathering in South Africa and hours of QUV exposure

THERMAL AGEING

Tests were carried out in general accordance with ASTM D-5510*: Standard Practice for Heat Aging of Oxidatively Degradable Plastics* in the dark in an oven at a temperature of 60°C. Procedure A: Gravity Convection Oven. Samples were withdrawn at time points corresponding to 100, 200, 300, and 400 hours for tensile testing and carbonyl index. An un-aged sample was kept as a control.

Samples were exposed to 60°C in an air-circulated oven by laying the samples on glass sheets. Thermal exposure to 60°C increases the reaction rate 8-fold from an ambient 30°C.

TENSILE TESTING

Tensile Properties were determined in general accordance with ASTM D882: *Standard Test Method for Tensile Properties of Thin Plastic Sheet (<1mm thickness).* Tensile properties of all the materials were measured on a Lloyd LRX tensile strength testing machine equipped with a 500 Newton load cell with a moving jaw of 50 ± 5 mm per minute. Samples 12mm x 75mm were tested with a crosshead speed of 50mm/min. Peak load and Extension at Break were determined from the instrument load cell. All samples were tested in the machine direction (MD) and transverse direction (TD).

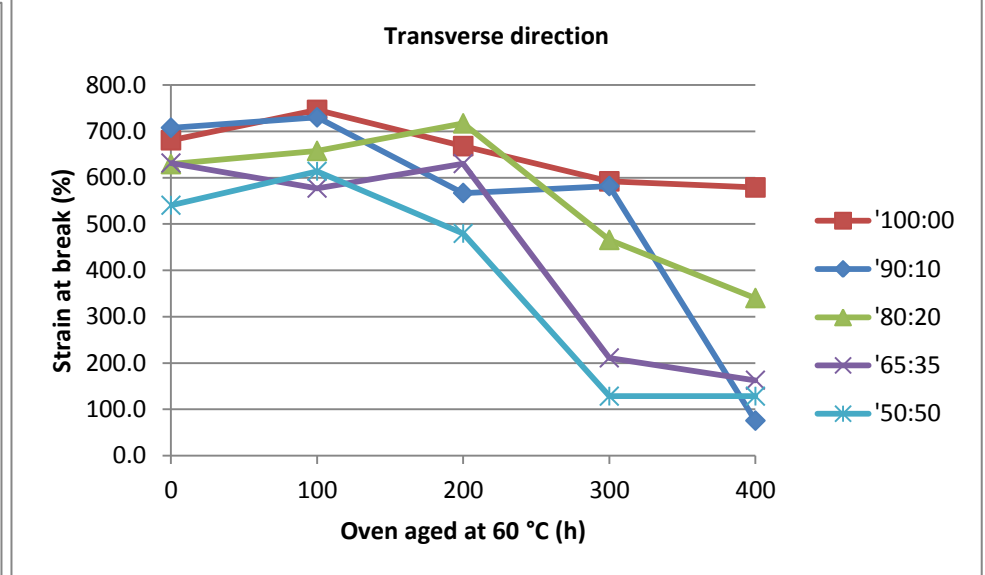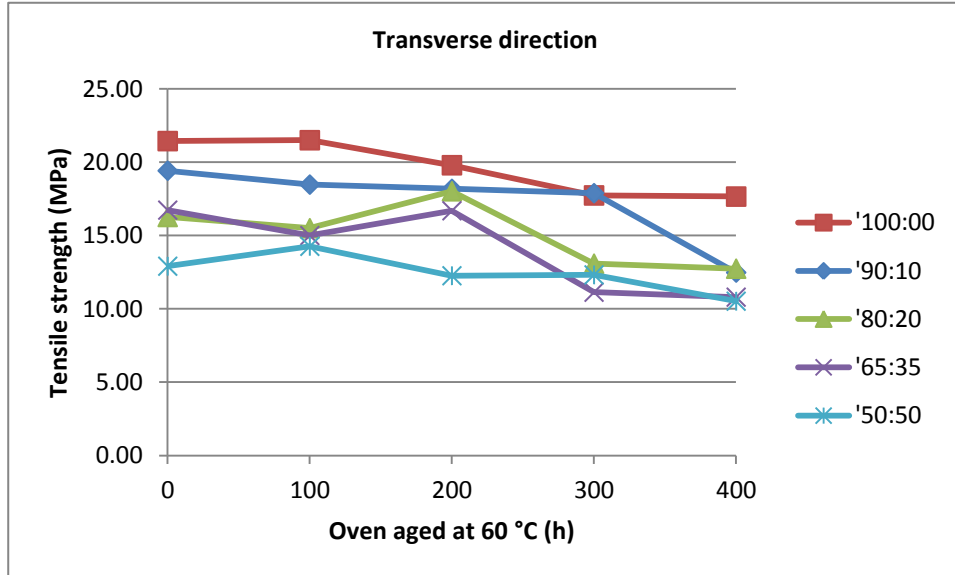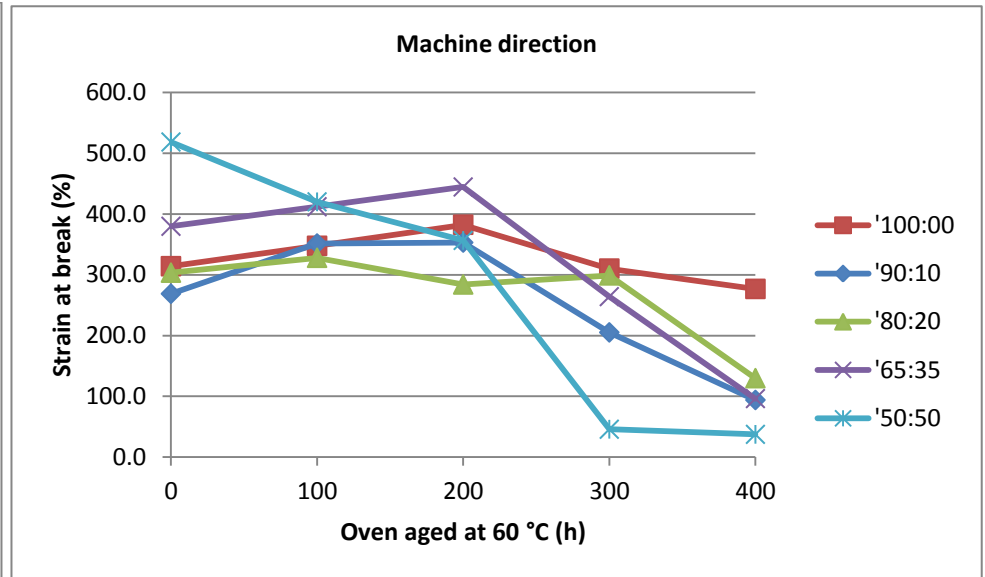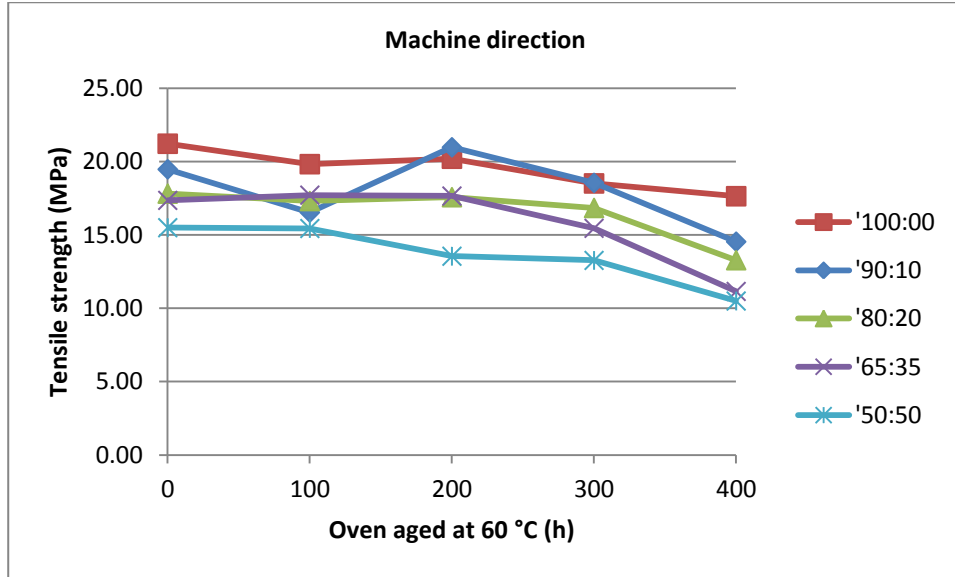**Tensile tests – strength & elongation after UV accelerated ageing**

100:0 MD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)	100:0 TD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	21.23	314.0	Average	0	21.44	680.7
	100	19.83	347.6		100	21.50	746.1
	200	20.21	382.3		200	19.80	667.9
	300	18.52	310.1		300	17.74	591.9
	400	17.65	276.7		400	17.66	578.8

100:0 MD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)	100:0 TD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	21.23	314.0	Average	0	21.44	680.7
	100	13.49	267.7		100	14.07	411.8
	250	16.02	11.7		250	14.59	5.4
	500	0.00	0.0		500	0.00	0.0
	750	0.00	0.0		750	0.00	0.0

90:10 MD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)	90:10 TD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	19.48	268.7	Average	0	19.42	707.7
	100	16.54	351.3		100	18.48	730.1
	200	20.98	353.0		200	18.19	566.8
	300	18.56	205.1		300	17.89	581.8
	400	14.55	93.9		400	12.48	75.5

90:10 MD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)	90:10 TD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	19.48	268.7	Average	0	19.42	707.7
	100	14.12	233.9		100	11.89	195.3
	250	12.94	13.0		250	8.94	1.8
	500	0.00	0.0		500	0.00	0.0
	750	0.00	0.0		750	0.00	0.0

80:20 MD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)	80:20 TD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	17.83	303.5	Average	0	16.27	629.2
	100	17.32	327.9		100	15.50	657.7
	200	17.58	284.0		200	18.02	717.1
	300	16.85	299.0		300	13.08	465.5
	400	13.29	129.9		400	12.74	340.1

80:20 MD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)	80:20 TD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	17.83	303.5	**Average**	0	16.27	629.2
	100	12.21	219.6		100	10.83	222.1
	250	13.06	27.9		250	13.72	16.8
	500	12.62	18.9		500	12.87	17.4
	750	0.00	0.0		750	0.00	0.0
65:35 MD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)	65:35 TD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	17.37	379.7	**Average**	0	16.74	631.6
	100	17.72	412.0		100	15.00	577.2
	200	17.66	444.5		200	16.69	630.2
	300	15.46	264.0		300	11.13	210.9
	400	11.16	96.2		400	10.80	162.7
65:35 MD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)	65:35 TD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	17.37	379.7	**Average**	0	16.74	631.6
	100	14.36	312.7		100	11.77	62.4
	250	14.47	21.2		250	14.30	10.7
	500	13.88	11.9		500	0.00	0.0
	750	7.27	3.5		750	0.00	0.0
50:50 MD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)	50:50 TD	Oven aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	15.50	518.4	**Average**	0	12.91	540.4
	100	15.44	420.0		100	14.27	613.6
	200	13.56	356.5		200	12.26	479.6
	300	13.27	45.8		300	12.32	128.3
	400	10.50	37.4		400	10.52	128.3
50:50 MD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)	50:50 TD	QUV aged (h)	Tensile strength (MPa)	Strain at break (%)
Average	0	15.50	518.4	**Average**	0	12.91	540.4
	100	11.32	338.0		100	9.68	145.7
	250	12.26	15.5		250	12.61	9.1
	500	12.53	23.8		500	12.48	8.7
	750	0.00	0.0		750	0.00	0.0

Table2: Averaged results of tensile test of oven aged and QUV aged samples.
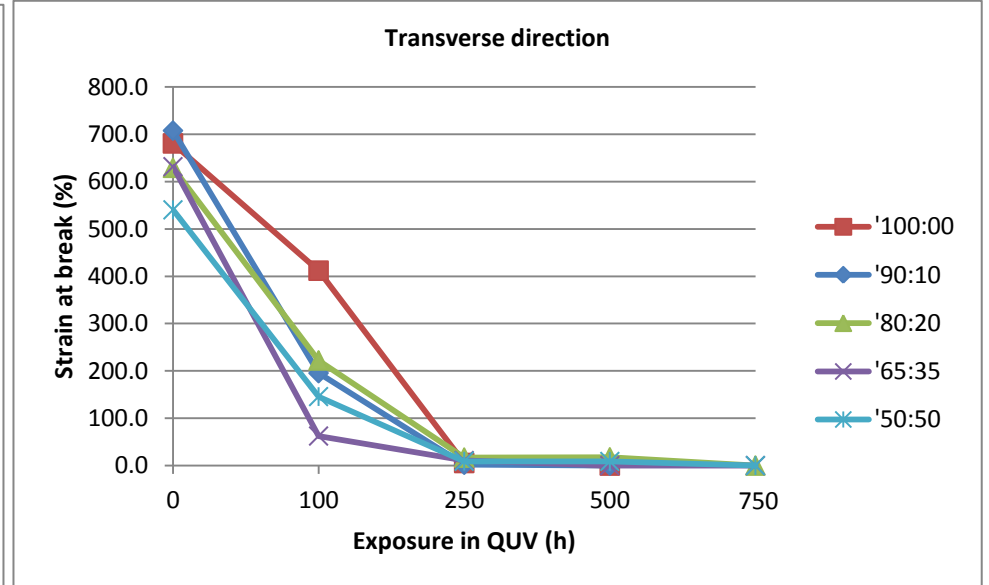
Results are graphically displayed collectively on the next page and individually in the Addendum, as are the detailed tensile-test results.

OVEN aged

Machine direction — Tensile strength (MPa) vs Exposure in QUV (h); legend: '100:00, '90:10, '80:20, '65:35, '50:50

Machine direction — Strain at break (%) vs Exposure in QUV (h); legend: '100:00, '90:10, '80:20, '65:35, '50:50

Transverse direction — Tensile strength (MPa) vs Exposure in QUV (h); legend: '100:00, '90:10, '80:20, '65:35, '50:50

Transverse direction — Strain at break (%) vs Exposure in QUV (h); legend: '100:00, '90:10, '80:20, '65:35, '50:50
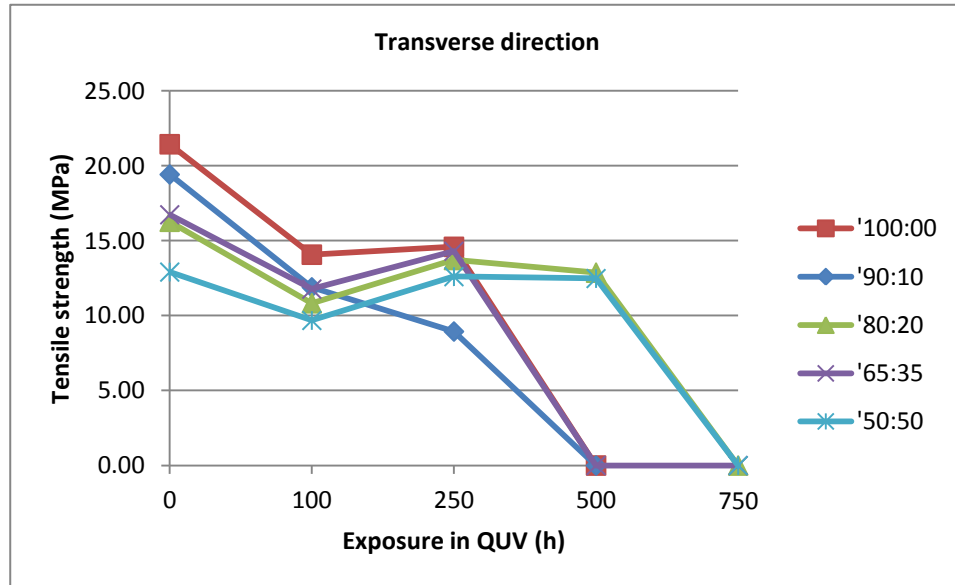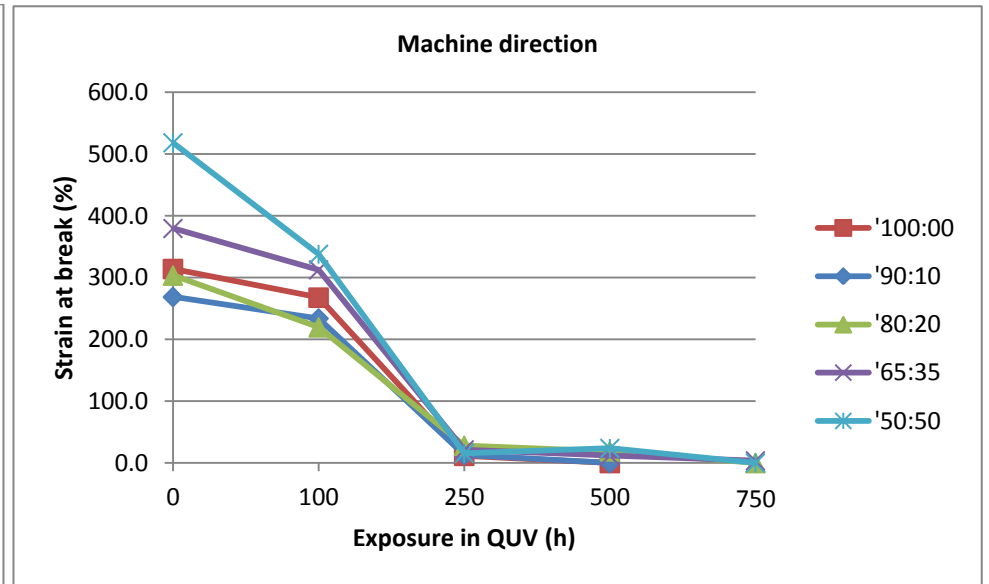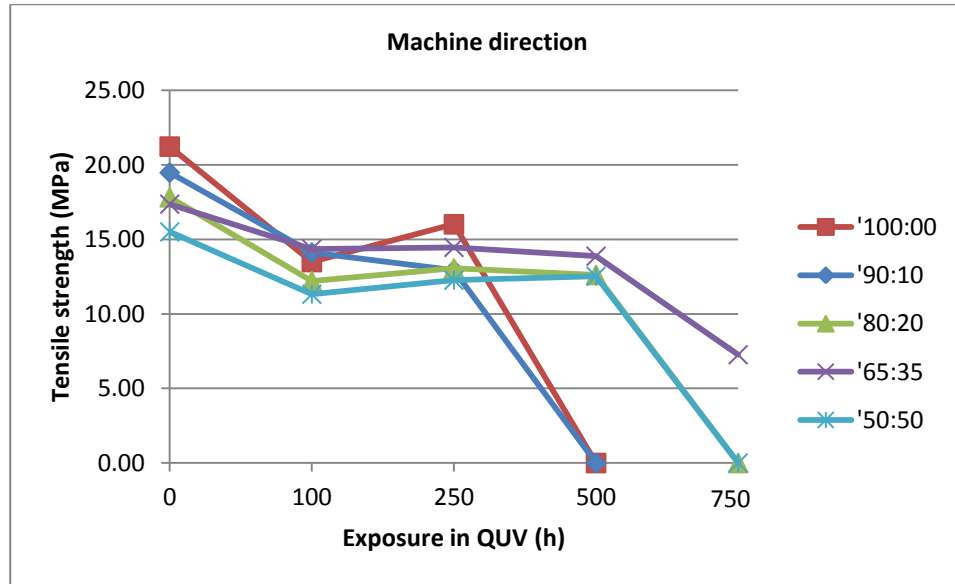
FTIR ANALYSIS

Fourier Transform Infrared (FTIR) is a common method of analysing the chemical composition of a product and is typically employed to monitor the presence of the chemical functional groups on a molecule. To obtain an infrared reading a sample is prepared in a translucent film or is physically mixed with a salt that when pressed will give a translucent window through which an infrared beam can be passed and the absorbance of the beam measured. A recent development in infrared technology is to make use of a photo-acoustic cell (PAS), which has the advantage that sample preparation is eliminated and a sample can be scanned in whatever form it appears. The sample is placed in an MTEC 300 chamber and flushed with ultra high purity helium. The resultant infrared spectrum is recorded on a Perkin Elmer Paragon 1000 FTIR.

The FTIR picks up absorbencies for each functional group. A single functional group yields more than one absorbance-bond due to stretching, rocking and vibrational movements. Some absorbencies may overlap and hence it is sometimes difficult to clearly relate an absorbance peak to only one bond. Peak areas are relative to the amount of a functional group present if the analysis is carried out under the same conditions each time. In the case of PAS FTIR this is the quantity of gas above the sample, the temperature of the sample, and the number of scans. A further feature of PAS FTIR is that the depth of analysis can be varied by varying the mirror speed of the infrared. The slower the mirror speed the deeper the penetration.

The samples were analyzed by means of photo acoustic Fourier Transform Infrared spectroscopy. The parameters used for the determination of each spectrum were the following:

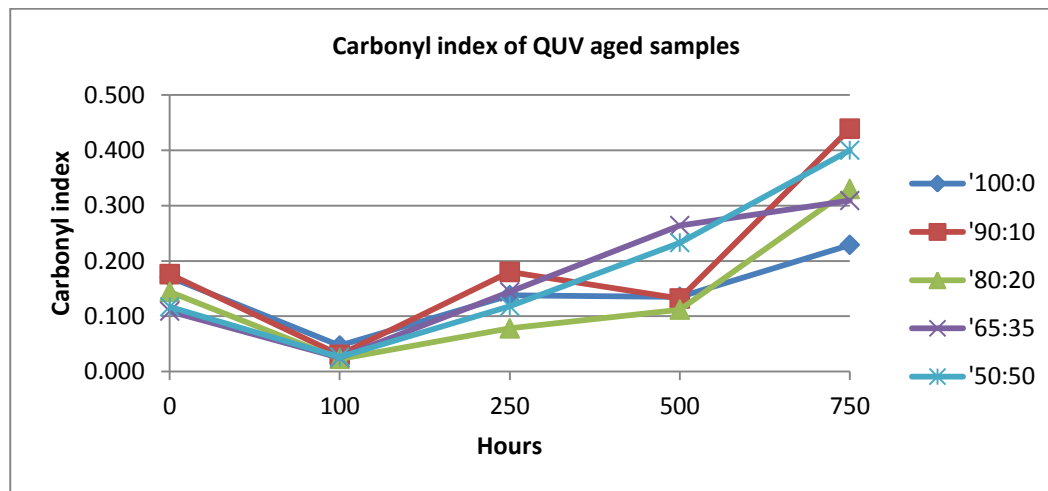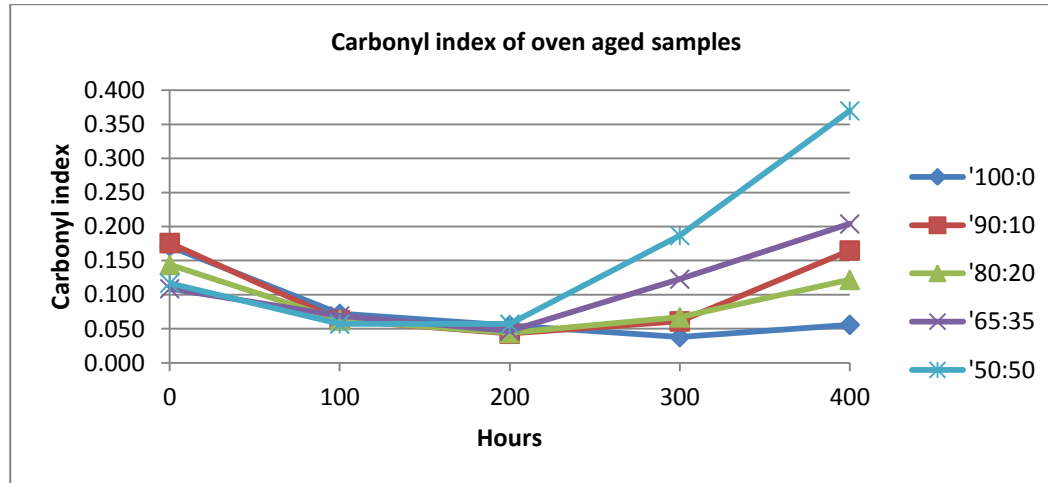|		
Mirror velocity (OPD)	=	0.1 cm/s
Resolution	=	8 cm^{-1}
Source aperture	=	maximum
Spectral Range	=	450 – 4 000 cm^{-1}
Number of scans	=	128
Sample reference	=	carbon black
Detector gas atmosphere	=	helium

A sample maximum 9 mm in diameter was placed in the sample holder cup, allowing a minimum amount of gas above the sample, which is flushed with helium to eliminate any air from the sample-compartment. A typical scan requires fifteen minutes scanning time. This allowed enough time for the sample temperature to equilibrate and hence, to obtain a quantitative measurement. Controlling the room temperature was not necessary.

All the infrared spectra were scanned from wave number 4000 to 450 cm^{-1} and the spectra were subsequently mathematically adjusted to compensate for the photo-acoustic effect.

The carbonyl ratio is determined by taking the area of the carbonyl peak C=O, and dividing it by the area of the -CH$_2$- peak. The results are tabulated below.

Sample	60°C oven exposure (h)				
	0	100	200	300	400
100:0	0.171	0.072	0.055	0.038	0.056
90:10	0.176	0.063	0.043	0.061	0.165
80:20	0.144	0.063	0.044	0.067	0.122
65:35	0.109	0.069	0.047	0.123	0.204
50:50	0.117	0.057	0.057	0.187	0.370
Sample	QUV exposure (h)				
	0	100	250	500	750
100:0	0.171	0.047	0.138	0.135	0.229
90:10	0.176	0.030	0.180	0.132	0.439
80:20	0.144	0.023	0.078	0.112	0.330
65:35	0.109	0.025	0.144	0.264	0.309
50:50	0.117	0.026	0.118	0.233	0.400

Table 3: Carbonyl index of films exposed to various environments and different lengths of period.

Carbonyl index of oven aged samples

Legend: '100:0, '90:10, '80:20, '65:35, '50:50

Carbonyl index of QUV aged samples

Legend: '100:0, '90:10, '80:20, '65:35, '50:50

It was impossible to measure the molecular-mass distribution of the films due to the solution being too turbid. Despite attempts to filter the solution hot, it was impossible to do this as the polymer tended to precipitate out. Therefore no molecular mass analysis was done.

Different results are observed with UV and heat ageing.

(a) UV ageing

The addition of d2w-containing film to pure regrind film actually improves the UV ageing properties of reground film. From a tensile-property point of view it can be seen that film containing no d2w film or only 10% d2w film, breaks down after 250 hours of UV light exposure. The elongation percentage of all films exposed to UV light decreases after 100 hours of exposure and is totally lost after 250hours of UV exposure irrespective of the addition of d2w film. The carbonyl index of all films exposed to UV light increases with exposure time.

(b) Heat ageing

The tensile strength of the five different samples blended with various ratios of d2w-containing reground film, decreased slightly with time of exposure. The film blown from pure reground film not containing d2w is the strongest, due to the type of polymer used in the d2w film. It appears that the strength of the d2w film polymer is weaker and hence the larger the percentage of the d2w reground film present, the weaker the resultant film. However, the percentage decrease in strength of each film with exposure time remains more or less the same, showing that the addition of d2w film to regrind film does not impair the tensile strength.

The elongation of the d2w film is greater than the pure reground film, and the resulting blends of d2w-containing regrind exhibit differing elongations as the concentration varies. Both the 50% and 35% containing d2w reground film show early elongation reduction after 300hours of 60°C exposure. The samples containing 20% and 10% d2w reground film show a lesser reduction in elongation, but in all cases more than the reground film containing no d2w.

The carbonyl index of the various films shows an initial decrease up to 200 hours thermal exposure but then the films degrade proportionately to the percentage of d2w-containing regrind present. The sample with the highest amount of d2w film shows the highest carbonyl index. Thermal-exposure of d2w-containing film results in reduced physical properties as the concentration of d2w film increases.

PART 2 - REGRIND FILM WITH THE ADDITION OF BASE STABILISATION.

Method

A quantity of LDPE polyethylene packaging material (circa 250 kilos) containing 1% d2w by mass was pelletised and added at 0, 5, 10 and 25% ratios to pellets of conventional recycled LLDPE which did not contain d2w.

A small amount of base-stabilisation was then added to the pellets, with the exception of a control, and all were then blown into sheet approximately 2mm (2 000 microns) in thickness. Base-stabilisation is normally added to prevent further breakdown of the polymer material during the extrusion process, which can be detrimental to the polymer due to high shear-rates and often due to slightly elevated temperatures being used to facilitate a faster output.

The base-stabiliser was a standard type used by many raw material suppliers of virgin polymer. The master batch was purchased from Performance Masterbatch as a 1:1 ratio of Irganox®1010 and Irgafos®168 in concentration of 8%. This was added to the compounding formulation, effectively giving an additional 0.16% base-stabilisation. The addition of base-stabilisation is warranted as the slight increase in price of the resulting compound ensures that minimal breakdown of polymer occurs in the reprocessing, whether the feedstock contains a pro-degradant additive or not.

The three test sheets with stabiliser and the control (recycled LLDPE film with no d2w pro-degradant additive) were prepared as follows:

100% recycled d2w film with 2% stabiliser yielding 0.16% base stabilisation;
100% recycled LLDPE film with no d2w additive (Control);
93% recycled LLDPE film + 5% d2w film + 2% stabiliser yielding 0.16% base stabilisation;
88% recycled LLDPE film + 10% d2w film + 2% stabiliser yielding 0.16% base stabilisation, and;
73% recycled LLDPE film + 25% d2w film + 2% stabiliser yielding 0.16% base stabilisation.

The sheets were then subjected to tests as described below.

Fluorescent UV Ageing

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The test was carried out in general accordance with ASTM D5208: *Standard Practice for Fluorescent Ultraviolet (UV) Exposure of photodegradable plastics*

The samples were exposed to ultraviolet radiation in a Q Panel QUV/se test apparatus, as described in Part 1 of this Report. Sheet specimens were withdrawn at time points corresponding to 144, 288, and 768 hours for tensile testing. An unexposed sample was retained as a control.

Thermal Ageing

The test was carried out in general accordance with ASTM D-5510: *Standard Practice for Heat Ageing of Oxidatively Degradable Plastics,* as in Part 1 of this Report. Samples were withdrawn at time points corresponding to 300 and 600 hours for tensile testing. In addition, an un-aged sample was retained as a control.

Tensile Testing

Tensile Properties were determined in general accordance with ASTM D638: *Standard Test Method for Tensile Properties of Thin Plastic Sheet (>1mm thickness).*

<u>Tensile tests – strength & elongation after UV accelerated ageing</u>

Tensile properties of the un-aged and aged materials were measured on a tensile strength testing machine with a moving jaw of 50 ± 5 mm per minute.

Sample	Yield strength (N/mm²)	Ext @ yield (mm)	Width (mm)	Thickness (mm)
Recyclate d2w extrusion	12.94	4.793	4.05	2.50
	13.70		4.00	2.52
	11.77	4.742	3.97	2.29
	11.61	4.739	4.08	2.58
	12.03	4.940	4.07	2.44
Average	**12.4**	**4.8**		
Standard deviation (%)	**7.1**	**192.9**		
Recyclate d2w extrusion (aged 144h)	12.16	4.166	4.11	2.25
	12.89	4.415	4.11	2.10
	12.86	3.699	4.11	2.12
Average	**12.6**	**4.1**		

Standard deviation (%)	**3.3**	**8.9**		
Recyclate d2w extrusion (aged 288h)	14.36	4.364	5.92	2.07
	12.75	3.995	6.08	2.49
	13.39	5.532	5.79	2.09
Average	**13.5**	**4.6**		
Standard deviation (%)	**6.0**	**17.3**		
Recyclate d2w extrusion (aged 768h)	10.82	3.668	6.12	2.75
	11.47	3.535	5.96	2.61
	13.34	4.454	4.04	1.98
Average	**11.9**	**3.9**		
Standard deviation (%)	**11.0**	**12.8**		

Table showing yield strength of recyclate d2w with stabiliser added versus UV exposure time

Sample	Yield strength (N/mm²)	Ext @ yield (mm)	Width (mm)	Thickness (mm)
Control recyclate without d2w	12.07	4.933	4.00	1.60
	11.12	4.183	4.00	1.69
			4.00	1.81
	9.23	1.874	4.00	1.98
	10.82	5.125	4.00	1.63
Average	**10.8**	**4.0**		
Standard deviation (%)	**24.2**	**52.6**		
Control recyclate without d2w (aged 144h)	11.53		6.00	2.25
	11.84	4.222	6.00	2.17
	12.51	3.554	6.00	2.23
Average	**12.0**	**3.9**		
Standard deviation (%)	**4.2**	**12.1**		
Control recyclate without d2w (aged 288h)	12.10	4.363	5.58	2.18
	12.51	3.989	6.09	2.08
	12.26	3.962	5.75	2.13
Average	**12.3**	**4.1**		
Standard deviation (%)	**1.7**	**5.5**		

Control recyclate without d2w (aged 768h)	11.16	4.872	3.98	1.70
	11.39	4.537	3.96	1.90
	11.54	4.871	3.96	1.61
Average	**11.4**	**4.8**		
Standard deviation (%)	**1.7**	**4.1**		
Recyclate containing 5% d2w	10.73	4.058	4.00	1.76
	10.82	6.757	4.00	2.06
	11.62	4.788	4.00	1.80
	12.57	4.872	4.00	2.04
	11.09	4.540	4.00	1.96
Average	**11.4**	**5.0**		
Standard deviation (%)	**6.7**	**20.6**		
Recyclate containing 5% d2w (aged 144h)	11.99	4.774	4.03	1.83
	12.13	4.423	3.97	1.75
	12.04	4.805	4.05	1.84
Average	**12.1**	**4.7**		
Standard deviation (%)	**0.6**	**4.5**		
Recyclate containing 5% d2w (aged 288h)	**12.1**	**4.1**	3.98	2.07
	12.2	**4.2**	3.98	1.91
	11.4	**4.2**	3.98	2.06
Average	**11.9**	**4.2**		
Standard deviation (%)	**3.6**	**1.3**		
Recyclate containing 5% d2w (aged 768h)	11.5	3.7	6.19	1.98
	11.5	4.2	6.15	2.09
	11.7	3.9	5.93	1.85
Average	**11.6**	**4.0**		
Standard deviation (%)	**1.0**	**6.3**		

Sample	Yield strength (N/mm²)	Ext @ yield (mm)	Width (mm)	Thickness (mm)
Recyclate containing 10% d2w	10.47	5.168	4.00	2.45
	11.18	5.823	4.00	2.56
	10.93	4.740	4.00	2.54
	11.06	5.024	4.00	2.58
	10.78	4.848	4.00	2.40
Average	**10.9**	**5.1**		
Standard deviation (%)	**2.5**	**8.3**		
Recyclate containing 10% d2w (aged 144h)	12.27	4.797	4.02	2.01
	11.98	5.045	3.97	1.91
	11.41	4.706	3.92	1.71
Average	**11.9**	**4.8**		
Standard deviation (%)	**3.7**	**3.6**		
Recyclate containing 10% d2w (aged 288h)	11.80	4.517	4.09	2.21
	11.35	4.258	4.10	2.03
	12.22	4.518	4.01	2.03
Average	**11.8**	**4.4**		
Standard deviation (%)	**3.7**	**3.4**		
Recyclate containing 10% d2w (aged 768h)	10.91	4.864	4.09	1.94
	11.47	4.655	3.88	1.84
	11.17	4.524	4.03	1.93
Average	**11.2**	**4.7**		
Standard deviation (%)	**2.5**	**3.7**		
Recyclate containing 25% d2w	10.87	4.783	4.00	2.35
	10.71	5.859	4.00	2.27
	11.58	4.557	4.00	2.32
	11.47	4.683	4.00	2.07
	12.17	5.964	4.00	2.07
Average	**11.5**	**5.3**		
Standard deviation (%)	**5.2**	**14.2**		
Recyclate containing 25% d2w (aged 144h)	12.66	4.705	4.05	1.93
	12.42	4.365	4.03	2.26
	11.67	4.366	3.99	2.20

Average	**12.0**	**4.4**		
Standard deviation (%)	**4.4**	**0.0**		
Recyclate containing 25% d2w (aged 288h)	11.89	4.517	4.05	1.96
	12.04	4.747	4.11	2.12
	11.84	4.507	4.08	2.21
Average	**11.9**	**4.6**		
Standard deviation (%)	**1.2**	**3.7**		
Recyclate containing 25% d2w (aged 768h)	11.18	4.805	4.07	1.92
	11.18	5.013	3.97	2.27
	11.71	5.047	4.01	2.19
Average	**11.4**	**5.0**		
Standard deviation (%)	**3.3**	**0.5**		

Table showing yield strength of recyclate containing various percentages of d2w with stabiliser added versus UV exposure time

UV ageing of repelletised d2w film considered in addition to the sheet samples described above
Film ageing under accelerated UV ageing as described above.
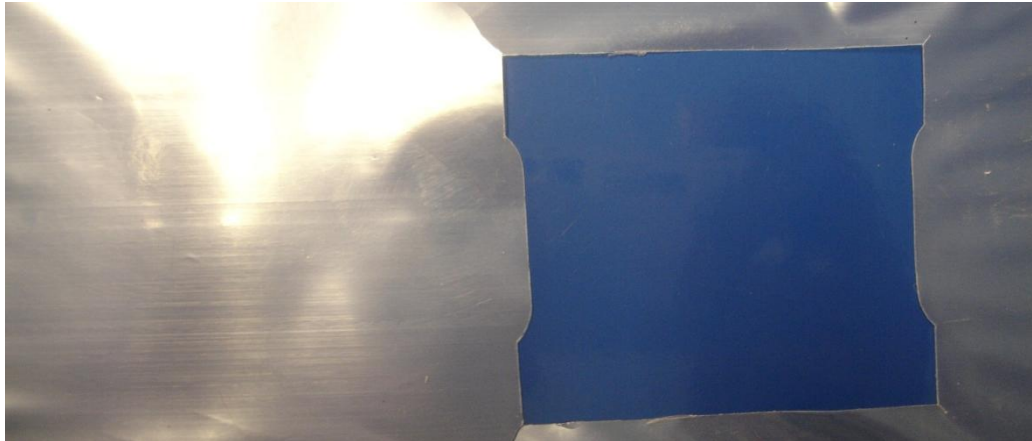
Aged film after 768h UV light with dumbbells punched out.

Film that has been aged 768h under accelerated UV weathering after the film has been agitated by hand.

Sample	Maximum load (N)	Breaking strength (N/mm²)	Ext @ max load (mm)	Elongation at break (%)	Width (mm)	Thickness (mm)
Control	7.0	21.27	72.820	316.60	6.00	0.06
	8.6	26.14	135.800	590.20	6.00	0.06
	8.7	26.32	100.200	435.60	6.00	0.06
	7.0	21.27	62.070	269.90	6.00	0.06
	8.2	24.88	106.800	464.20	6.00	0.06
Average	**7.9**	**24.0**	**95.5**	**415.3**		
Standard deviation (%)	**10.5**	**10.6**	**30.5**	**30.5**		
d2w film (768h)	1.4	5.29	0.586	2.76	6.00	0.05
	6.1	22.47	1.745	8.22	6.00	0.05
	5.8	21.37	1.579	7.44	6.00	0.05
	4.4	16.30	1.036	4.88	6.00	0.05
	0.5	1.98	0.194	0.91	6.00	0.05
Average	**3.6**	**13.5**	**1.0**	**4.8**		
Standard deviation (%)	**69.4**	**69.4**	**63.6**	**63.6**		

## Tensile tests – strength & elongation after heat-ageing

Tensile properties were measured on a tensile strength testing machine with a moving jaw of 50 ± 5 mm per minute.

Sample	Maximum load (N)	Breaking strength (N/mm²)	Ext @ max load (mm)	Width (mm)	Thickness (mm)
Recyclate d2w extrusion	131.1	12.94	4.793	4.05	2.50
	138.1	13.70		4.00	2.52
	107.0	11.77	4.742	3.97	2.29
	122.2	11.61	4.739	4.08	2.58
	119.5	12.03	4.940	4.07	2.44
Average	**123.6**	**12.4**	**4.8**		
Standard deviation (%)	**9.6**	**7.1**	**192.9**		
Control recyclate without d2w	77.2	12.07	4.933	4.00	1.60
	75.2	11.12	4.183	4.00	1.69
	43.4			4.00	1.81
	73.1	9.23	1.874	4.00	1.98
	70.6	10.82	5.125	4.00	1.63
Average	**67.9**	**10.8**	**4.0**		
Standard deviation (%)	**20.5**	**24.2**	**52.6**		
Recyclate containing 5% d2w	75.6	10.73	4.058	4.00	1.76
	89.2	10.82	6.757	4.00	2.06
	83.6	11.62	4.788	4.00	1.80
	102.6	12.57	4.872	4.00	2.04
	87.0	11.09	4.540	4.00	1.96
Average	**87.6**	**11.4**	**5.0**		
Standard deviation (%)	**11.3**	**6.7**	**20.6**		
Recyclate containing 10% d2w	102.6	10.47	5.168	4.00	2.45
	114.5	11.18	5.823	4.00	2.56
	111.1	10.93	4.740	4.00	2.54
	114.2	11.06	5.024	4.00	2.58
	103.5	10.78	4.848	4.00	2.40
Average	**109.2**	**10.9**	**5.1**		
Standard deviation (%)	**5.3**	**2.5**	**8.3**		

Recyclate containing 25% d2w	102.2	10.87	4.783	4.00	2.35
	97.3	10.71	5.859	4.00	2.27
	107.4	11.58	4.557	4.00	2.32
	94.9	11.47	4.683	4.00	2.07
	100.8	12.17	5.964	4.00	2.07
Average	**100.1**	**11.5**	**5.3**		
Standard deviation (%)	**5.4**	**5.2**	**14.2**		

The recyclate film blown from 100% d2w film degrades under the equivalent of two years outdoor UV exposure in South Africa, with an almost 50% reduction in tensile strength, and once the film is agitated it falls apart. This does not occur with the recycled LLDPE control sample or with blends of this and certain percentages of recycled d2w film (see graph below), so the addition of d2w has no detrimental effect.

UV aged	Yield strength (N/mm²)	Ext @ yield (mm)
Recyclate d2w extrusion	12.4	4.8
d2w 144h	12.6	4.1
d2w 288h	13.5	4.6
d2w 768h	11.9	3.9
Control recyclate without d2w	10.8	4.0
144h	12.0	3.9
288h	12.3	4.1
768h	11.4	4.8
Recyclate containing 5% d2w	11.4	5.0
144h	12.1	4.7
288h	11.9	4.2
768h	11.6	4.0
Recyclate containing 10% d2w	10.9	5.1
144h	11.9	4.8
288h	11.8	4.4
768h	11.2	4.7
Recyclate containing 25% d2w	11.5	5.3
144h	12.0	4.4
288h	11.9	4.6
768h	11.4	5.0
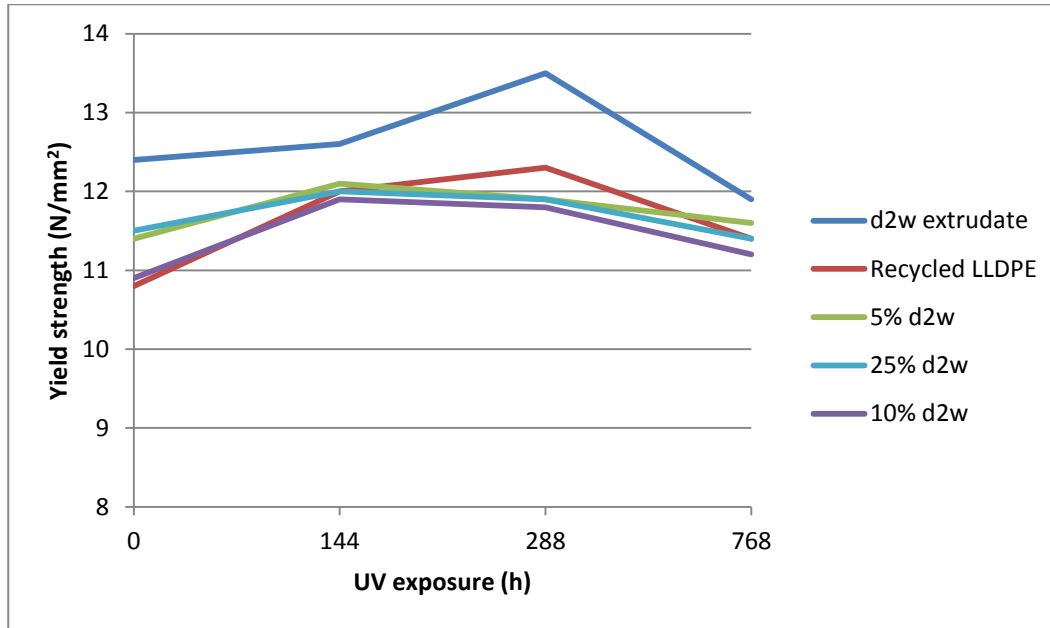
Graph showing yield strength of recyclate containing various percentages of d2w with stabiliser added versus UV exposure time

Yours faithfully,

Dr. A. H. A Roediger