APPENDIX B

RECYCLED POLYETHYLENE RESINS

APPENDIX B – RECYCLED POLYETHYLENE RESINS

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B.1 INTRODUCTION

There were about 50 different recycled polyethylene suppliers identified and many were contacted for samples. A list can be found in Section B.8. The companies that chose to participate in this study by providing one or more recycled samples for this part of the study were:

Berou International Inc.
Blue Ridge Plastics, LLC
Clean Tech, Inc.
Custom Polymers Inc.
Entropex, Inc.
Envision Plastics
KW Plastics, Recycling Division
Polychem Products, Ltd
Trademark Plastics Corporation

B.2 POST-INDUSTRIAL RECYCLED (PIR) POLYETHYLENE

This is a large category that includes scrap from processes such as pipe, sheet, thermoforming, injection molding, blown film, tubing and more. This includes low density, linear low density, linear medium density, and high density (homo- and co-polymer). The molecular weight also varies from injection molding grade (low Mw, high MI) to thermoforming or blown film resins (high Mw, low MI).

There are certainly resins which would be appropriate for incorporation into pipe available from the post-industrial market. However, there is a downside. Post-industrial is sold mainly through brokerage firms, and is commonly sold on a lot-to-lot basis. This means that reliable and continuous waste streams are not commonly found. Additionally, it is often in a bulk form and/or co-mingled with different grades of PE. The result is that it is used mostly in non-critical applications by plastic processors that have the capabilities to accommodate different grades of polyethylene.

Despite the limitations mentioned above, three PIR polyethylene samples were received for evaluation in this study. Two (HDPE and LDPE) were provided by a reprocesser that also produces post-consumer polyethylene. The third (MDPE) was regrind scrap from a manufacturer of geomembranes for landfills. Properties of each of these recycled resins are found in Table B-1.

Notice that each of these has stress crack resistance (15% NCTL) higher than most, if not all the current AASHTO resins for pipe. They are also much higher in cracking resistance than post-consumer HDPE. Therefore, these resins could be useful for enhancing the properties of post-consumer HDPE. They are also much lower in density, which would limit how much could be used in a blend. The density for the low density material is actually higher than the density of the MDPE. This is due to the high level of inorganic fillers displayed by the % Ash. In fact, each of the 3 density values are misrepresented because of fillers in the case of the HD and LD, and carbon black in the case of the MD sample. Alternatively, the density can be calculated from the yield stress through the relationship:

$$\text{Yield Stress} = 81{,}250\ (\text{Density}) - 73{,}500$$

The calculated density values for the HD, MD, and LD are 0.943, 0.937, and 0.925 g/cm^3, respectively. One can also correct for the carbon black from the MD sample because each 1 percent black increases the density 0.0044 g/cm^3. This also produced a calculated value of 0.937 g/cm^3.

Some blends were prepared with these resins, and their properties will be presented and discussed in Appendix C.

Table B-1 - Post Industrial Recycled Resin Properties

Property	Supplier/Resin/Type		
	Supplier 5 HDPE Reprocessed	Supplier 9 MDPE Regrind	Supplier 5 LDPE Reprocessed
Density g/cm^3	0.970	0.942	0.952
Melt Index g/10 min	0.32	0.66	0.80
MFR (21.6/2.16kg)	101	46	34
% Volatiles	0.24	--	0.18
% Color	0.28	1.05	0.15
% Ash	3.69	0.05	3.75
Yield Strength (psi)	3143	2631	1686
Break Strain (%)	628	662	727
15% NCTL (hrs)	104	>800	>300
OIT (min)	18.2	61.4	6.3

B.3 POST-CONSUMER RECYCLED (PCR) HIGH DENSITY POLYETHYLENE

This is a smaller category, in terms of different resins, that includes primarily recycled bottles and high-strength shopping or trash bags. The volume of good recycled bags is low because the bulk density (volume/weight ratio) is low and the high quality bags are usually contaminated with lower quality LDPE bags. Additionally, the volume of plastic bags is shrinking because their use is being legislated against in a growing number of communities throughout the United States.

The bottles can either be natural or colored. The natural bottles are most often the ½ to 1 gallon water, juice, or milk jugs. They are made from HDPE homopolymer, which is a resin with high strength and poor stress crack resistance.

The colored bottles include those containing liquid detergent, cleaners, shampoos, fabric softeners, and others marked with a number 2 recycling code. The resin used in colored bottles is a HDPE co-polymer which is not as strong as the homopolymer but has better cracking resistance.

Both the natural and colored HDPE resins are available as regrind (chips) or reprocessed (pellets). The reprocessed pellets have the advantage of being melt-filtered during the pelletizing process. This is essentially one additional purification step. The colored bottle recycled resin contains a significant amount of natural bottles in it. There is an increasing number of recyclers who are hand-separating the natural bottles from the mixed color bottles because the natural resin has significantly higher value on the recycled resin market. The difference can be $0.10 per pound, or more.

Most of the samples found during this study came through contact with the Association of Post-Consumer Plastic Recyclers (APR).

Nineteen samples of PCR-HDPE were received from six member companies of the APR and 2 non-members. The samples included natural regrind (1), natural reprocessed (3), mixed color regrind (5), mixed colored reprocessed (7), and 3 special blends, that project personnel are calling mixed color plus. Two of these are mixed color reprocessed with added high molecular weight HDPE to assist with processing, and improve properties such as impact strength and stress crack resistance. The third is a blend of mixed color post-consumer with post-industrial.

These resins were made into plaques and characterized by a variety of tests. The full test reports for these materials are found in Section B.5. The results were originally generated on plaques made from the ‘as-received’ pellets. Test results indicated that further blending was necessary to obtain homogeneous material for characterization. This is reasonable because single screw production lines are not as well suited for blending as a twin screw. If the recyclers were to improve the mixing on their extruders, the changes could cause more thermal-oxidative degradation to the material. Therefore, the mixed color regrinds and reprocessed materials were further blended and re-characterized. In general, the regrind samples received were melt-blended at least twice and the reprocessed samples were further blended at least one additional time.

Two companies provided both regrind and reprocessed material. A comparison of the test results show the effects of re-processing on the recycled material.

B.3.1 PCR Natural Resin

The resin properties for Post-Consumer Natural Recycled HDPE have been summarized in Table B-2. TRI repro was a blend of the others made in-house as an "average" sample. A milk bottle was also tested for comparison.

Table B-2 - Post-Consumer Natural Recycled Polyethylene Properties

Property	Supplier/Resin Type					
	Supplier 2 Repro	Supplier 2 Repro 2	Supplier 3 Repro	Supplier 6 Regrind	TRI Repro	Milk Bottle
Density g/cm^3	0.957	0.960	0.955	0.957	0.960	0.958
Melt Index g/10 min	0.64	0.81	0.57	0.68	0.79	0.74
MFR (21.6/2.16kg)	86	76	96	91	71	75
% Volatiles	0.06	--	0.06	--	0.08	0.04
% Ash	0.16	0.05	0.08	0.14	0.06	0.04
Yield Strength (psi)	4380	4489	4304	4437	4523	4316
Break Strain (%)	206	229	75	118	365	114
15% NCTL (hrs)	3.4	1.8	3.8	5.7	2.0	5.4
OIT (min)	15	9	27	15	--	23
OITemp (°C)	236	--	245	238	--	--

Observations from the summary table include:

The density and melt flow values are higher than typically found for AASHTO pipe resin. AASHTO pipe resins are typically around 0.950 g/cm^3 and 0.15 g/10 min.

The volatiles and ash contents are low. This demonstrates that recycled natural resin is very clean.

The high yield stress is due to the higher density. Yield stress and density are linearly related.

The % strain-at-break was low compared to virgin materials (>500%). This property can be considered a flaw detector, since every break in a tensile test occurs at a flaw. These results indicate that the small amount of particles present in the recycled result in early breaks. In turn, the flaws can also be initiators of stress cracks in the resultant pipe.

The 15% NCTL times are low, which is a result of the high density and the fact that milk bottle resin is a homopolymer.

The OIT and OITemp values are indicative of stabilizer concentration, but how much is there cannot be determined without knowing the specific additive package and what the relationship between OIT and concentration is for that specific package. However, the data do indicate that there is some anti-oxidant protection remaining in the recycled HDPE.

The advantage of this recycled resin is that it is clean and strong, the disadvantages include the cost and the poor cracking resistance.

B.3.2 PCR Mixed Color Resin

The most samples obtained fall into this category. There were 15 different samples from 8 different suppliers. There were 5 regrind and 10 reprocessed resins. And, of the 10 reprocessed, three had something else added. Suppliers 2 and 3 sent samples with added HMW polyethylene to improve processing and stress crack resistance. Supplier 5 sent a product with additional PIR-HDPE added to improve its properties. Suppliers 1 and 3 sent samples of regrind at different times, so the consistency of their products can be examined.

A summary of the properties of all the mixed color resins received is found in Table B-3. This table provides a snap-shot of the PCR resins available in the first half of 2007. The sample called TRI Repro 1 was a batch prepared in house on the twin screw extruder. All the available mixed color reprocessed samples were combined to prepare 20 lbs of resin that was basically an average of the samples received.

The results in this table allow comparisons, including:

1. Consistency over time as displayed by the two samples of regrind from Suppliers 1 and 3.
2. Regrind to Reprocessed as displayed by samples from Suppliers 2 and 3.
3. Reprocessed with and without added high molecular weight polyethylene. See Suppliers 2 and 3.
4. The effect of added PIR-HDPE from Supplier 5.

One can also look at all of the resins to get an idea of the industry-wide variability in properties.

Table B-3 - Post-Consumer Mixed Color Recycled Polyethylene Properties

Property	Supplier/Resin/Type					
	1 Supplier 1 Regrind	2 Supplier 1 Regrind 2	3 Supplier 2 Regrind	4 Supplier 2 Repro	5 Supplier 2 Repro +	6 Supplier 3 Regrind
Density g/cm^3	0.948	0.960	0.962	0.946	0.957	0.961
Melt Index g/10 min	0.37	0.48	0.64	0.56	0.53	0.57
MFR (21.6/2.16kg)	93	83	75	103	91	94
% Volatiles	0.2	--	0.2	0.2	--	0.1
% Color	0.4	0.2	0.3	0.1	0.2	0.4
% Ash	0.8	1.4	0.9	1.3	1.2	0.9
% PP	4.1	3.2	4.4	6.3	3.1	4.8
Yield Strength (psi)	3327	3441	4037	3732	3602	3966
Break Strain (%)	26	158	27	20	23	27
15% NCTL (hrs)	5.2	8.0	5.9	12.2	14.8	4.5
OIT (min)	39	13	13	12	10	10
OITemp (°C)	249	236	236	235	235	238

Table B-3 - Continued

Property	Supplier/Resin Type					
	7 Supplier 3 Regrind 2	8 Supplier 3 Repro	9 Supplier 3 Repro +	10 Supplier 4 Repro	11 Supplier 5 Repro	12 Supplier 5 Repro+
Density g/cm^3	0.960	0.952	0.955	0.955	0.957	0.953
Melt Index g/10 min	0.52	0.44	0.38	0.56	0.43	0.31
MFR (21.6/2.16kg)	97	117	122	88	101	80
% Volatiles	--	0.2	0.52	0.2	0.2	0.15
% Color	--	0.3	0.2	1.3	0.4	0.2
% Ash	1.5	1.0	1.0	1.3	1.4	0.4
% PP	--	2.8	5.3	2.5	3.2	2.1
Yield Strength (psi)	3613	3876	3539	3616	3995	4007
Break Strain (%)	171	72	9	110	50	302
15% NCTL (hrs)	7.1	4.6	10.1	8.9	6.1	10.7
OIT (min)	12	10	10	13	9	12
OITemp (°C)	235	238	236	238	234	237

Table B-3 - Continued

Property	Supplier/Resin Type			
	13 Supplier 6 Repro	14 Supplier 7 Repro	15 Supplier 8 Repro	16 TRI Repro 1
Density g/cm^3	0.959	0.947	0.958	0.960
Melt Index g/10 min	0.59	0.45	0.32	0.54
MFR (21.6/2.16kg)	89	106	113	83
% Volatiles	0.2	0.3	0.3	--
% Color	0.0	0.0	--	0.4
% Ash	0.9	1.2	1.5	1.2
% PP	0.8	2.3	5.6	5.7
Yield Strength (psi)	3825	3712	3625	3685
Break Strain (%)	155	99	107	46
15% NCTL (hrs)	5.9	6.1	6.4	8.8
OIT (min)	12	15	14	12
OITemp (°C)	236	235	242	239

B.3.2.1 Density

The density of polyethylene is directly related to the percent crystallinity. Figure B-1 shows the densities of all the samples. Certain properties are governed by the density including strength, flexural modulus, hardness, elongation, and to a lesser extent stress crack resistance. Density is also an important issue for stabilization. As the density decreases, the need for better stabilization increases, due to the increase in free volume. It is a fundamental property for specifying virgin PE resins.

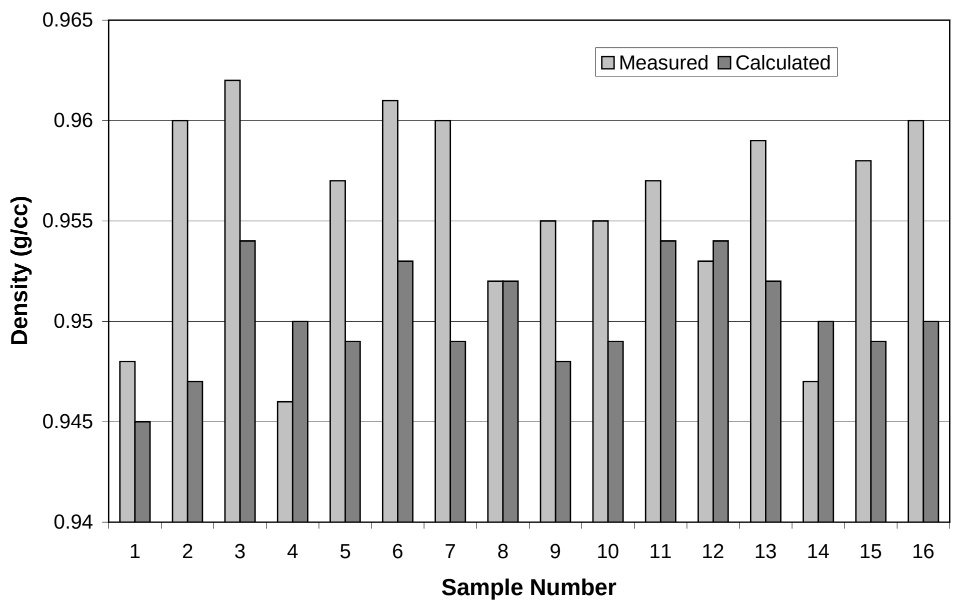

Figure B-1 - Density Values for PCR Mixed Color Resin Samples

However, as mentioned before in Section B-2, the density is misleading because recycled samples contain some color and more ash than virgin, both of which contribute to the density.

Figure B-2 shows the theoretical line of yield stress versus density, contrasted with the densities and yield values from Table B-3. The theoretical line was derived by data presented in PPI TR-43. Notice that the presented results on the PCR mixed color samples are not anywhere close to a linear fit. This demonstrates that the density is not reliable for these resins. Of course, the yield stress values can also be affected by the presence of fillers, but color is not reinforcing, and one rarely finds reinforcement fillers in commodity HDPE resins. Therefore, it is believed that the yield stress is a more reliable indicator of the recycled resins'density. For this reason, values calculated from the equation in Figure B-2 are also shown in Figure B-1. The calculated values ranged from 0.945 to 0.953 g/cm^3 and probably vary with milk bottle content.

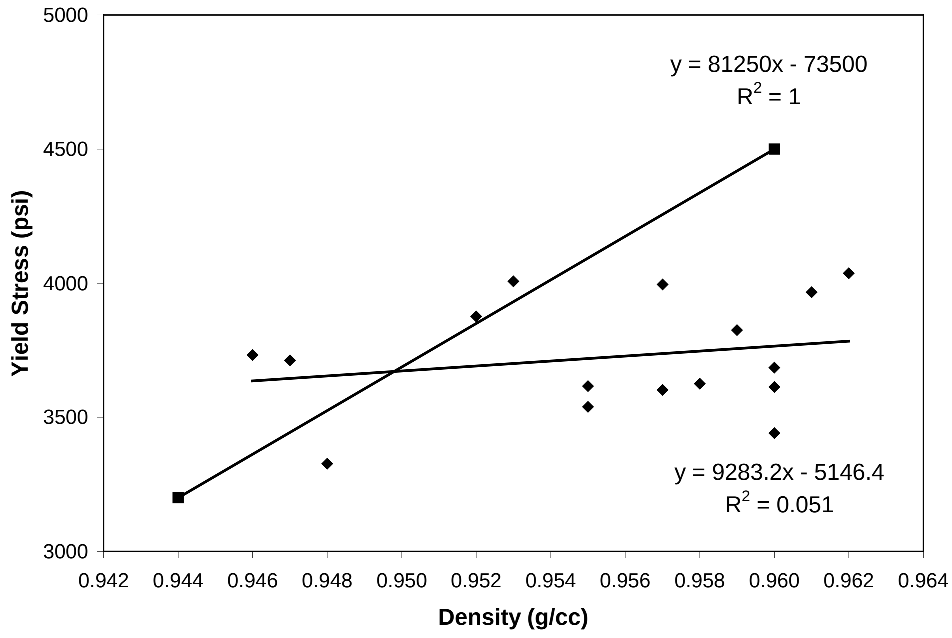

Figure B-2 - Yield Stress Versus Density for PCR Mixed Color Resin Samples

As far as a specified property, one should know that the material is typical. Therefore, a range of 0.945 to 0.960 g/ cm^3 should be adequate. And, since this is a property the recycler should be measuring anyway, a frequency of once per shift is reasonable.

B.3.2.2 Melt Index

The melt index (MI) test measures the flow rate of molten polyethylene as it passes through a standard sized orifice at a fixed temperature and load. The melt index refers to a test performed at 190°C under a load of 2.16 Kg. Tests at different loads are usually called Melt Flow Rate (MFR) tests. The test is a basic indicator of resistance to flow and is a fundamental property of polyethylene. Different processes use different MI resins. For example, injection molding requires fast turnaround and low viscosity resins. Injection molding resins are in the 10 – 100 g/10 min range. On the other hand, blow molding thick films requires great melt strength which comes with high viscosity. These resins are around a MI value of 0.1 g/10 min.

The melt index values for the samples are shown in Figure B-3.

The values have a range from 0.31 g/10min to 0.64 g/10 min. This property relates to the average molecular weight of the polyethylene and differs partly due to the percentage of milk bottle resin in the mixed color resin. The milk bottle homopolymer has a melt index of about 0.75 g/10 min, so the MI will increase with increasing milk bottle content. To prevent too much homopolymer in the mixed color, the Melt Index should have a maximum value of 0.60 g/10 min. This is another property that the recyclers should be measuring regularly, so a frequency of one per shift is reasonable.

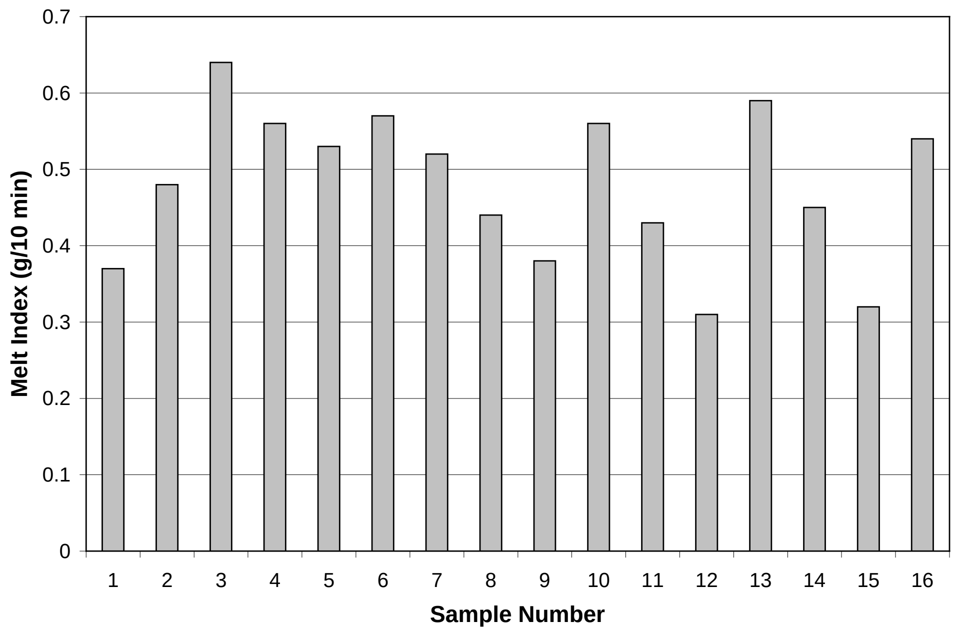

Figure B-3 - Melt Index Values for PCR Mixed Color Samples

B.3.2.3 Melt Flow Ratio

The melt index is a measure of the materials viscosity at one specific shear stress. However, polyethylene is a shear thinning material, which means its viscosity changes as a function of the force placed on it. A way to get more information is to run the melt flow test under 2 different applied loads, and ratio the results. This was done and the results are found in Figure B-4.

One common practice is the measure the flow rate at 2.16 and 21.6 Kg (sometimes called the high load melt index or HLMI). The ratio of high load value to low load is the melt flow ratio. It gives a general indication of the molecular weight distribution and can be helpful to processors.

The mixed color samples ranged from 75 to 122 in melt flow ratio. Interestingly, Sample 3 had the highest density, melt index, yield strength and the lowest melt flow ratio. This is a strong indication that this sample has the most milk bottle homopolymer in it. This property is not normally specified for common extrusion operations.

B.3.2.4 Yield Stress

For most polyethylenes, the yield stress is directly related to the density. In this case, this value is more useful than the density, due to fillers that make the density unreliable.

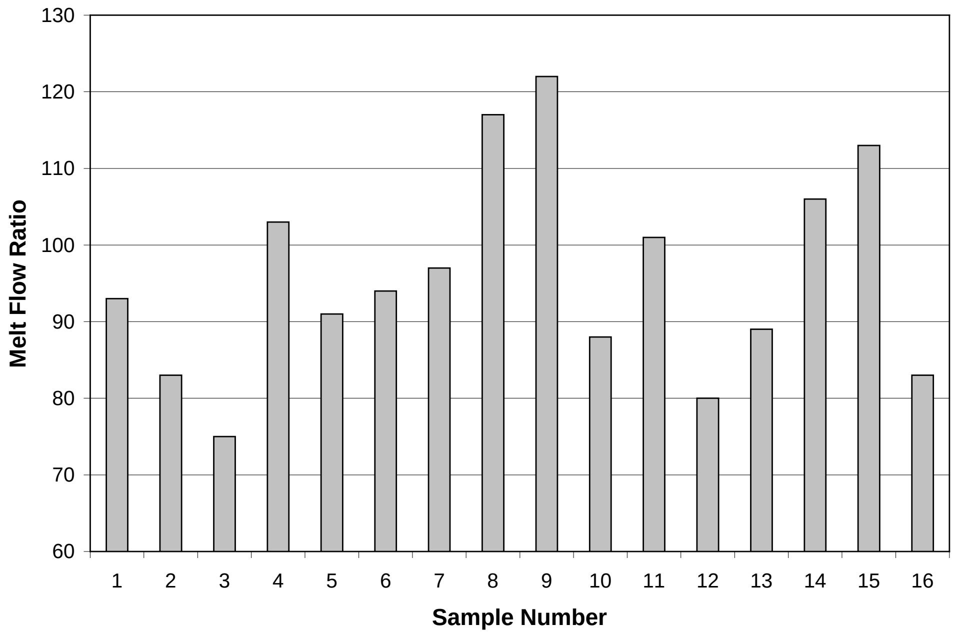

Figure B-4 - Melt Flow Ratio Values for PCR Mixed Color Samples

The yield stress values are shown in Figure B-5. The values range from 3327 to 4037 psi. Most of the samples are between 3500 and 4000 psi, which is a good match with AASHTO approved pipe resins. All the samples in the table were tested with 5 replicates except samples 8, 10, 11, 12, and 13, which were tested with 10 replicates. A minimum value of 3500 psi should be established to prevent too much low quality LDPE from being part of the blend. This value also correlates with the minimum density requirement of 0.948 g/cm^3. This test does not need to be done as frequently as density and MI.

B.3.2.5 Strain-at-Break

The strain-at-break values are shown in Figure B-6. The strain-at-break values may be the most important ones in terms of manufacturing a high quality pipe. When a tensile test is performed, the specimen always breaks at a defect of some kind. Virgin resins have few defects and they stretch to hundreds of percent before a tiny imperfection creates a failure. On the other hand, samples with high numbers of gels or inclusions, or particulates may break much earlier. The strain-at-break is affected by both the number and the size of the defects. Notice the large variability in the results as shown by the error bars, which represent one standard deviation from the mean. High scatter is something almost always associated with tests sensitive to flaws. The numbers and sizes of flaws or defects are by nature random and scattered. Some test specimens naturally have more or fewer flaws.

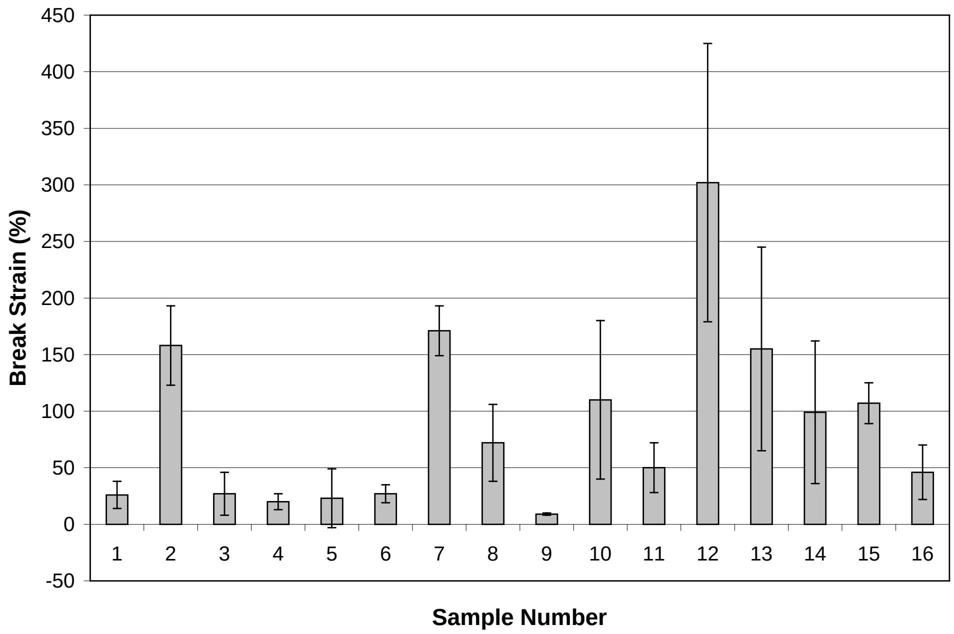

Figure B-5 - Yield Stress Values for PCR Mixed Color Samples

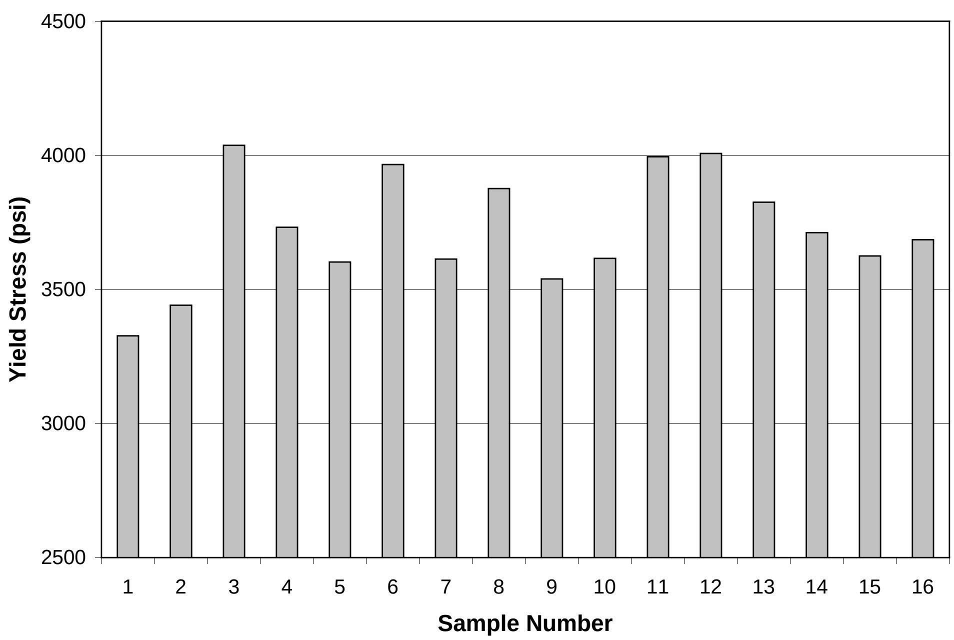

Figure B-6 - Strain-at-Break Values for PCR Mixed Color Samples

In terms of stress crack resistance, there is a concept of the critically sized defect. This means that only the flaws of a particular size or bigger will initiate a stress crack. If one can keep the number of critically sized defects low, the tendency for cracking will be reduced.

The results show a range from 9 % to 302 %. This variability is most likely due to the size and amount of contaminants in the recycled resin. It may also reflect the various cleaning operations or how well a particular supplier melt filtered the resin.

Earlier results showed that a strain-at-break of over 100% could be obtained simply by melt filtration at an equivalent of a 150 mesh screen. Later, results on regrind with silicone rubber present showed that melt filtration was not effective. Therefore, requiring a value of 100% should result in recycled resins that are both low in silicone rubber and well filtered. Additionally, the specification may require that all five specimens have a break strain over 100%.

B.3.2.6 Percentage Ash and Color

The next two figures (Figure B-7 and B-8) show the % Ash and the % Color for the mixed color resins. The percent color + ash was determined by the muffle furnace technique (ASTM D4218) in aluminum pans. The ash content was also determined with the use of a muffle furnace by ASTM D5630, but porcelain crucibles were used. The percent color was derived from the other two measurements.

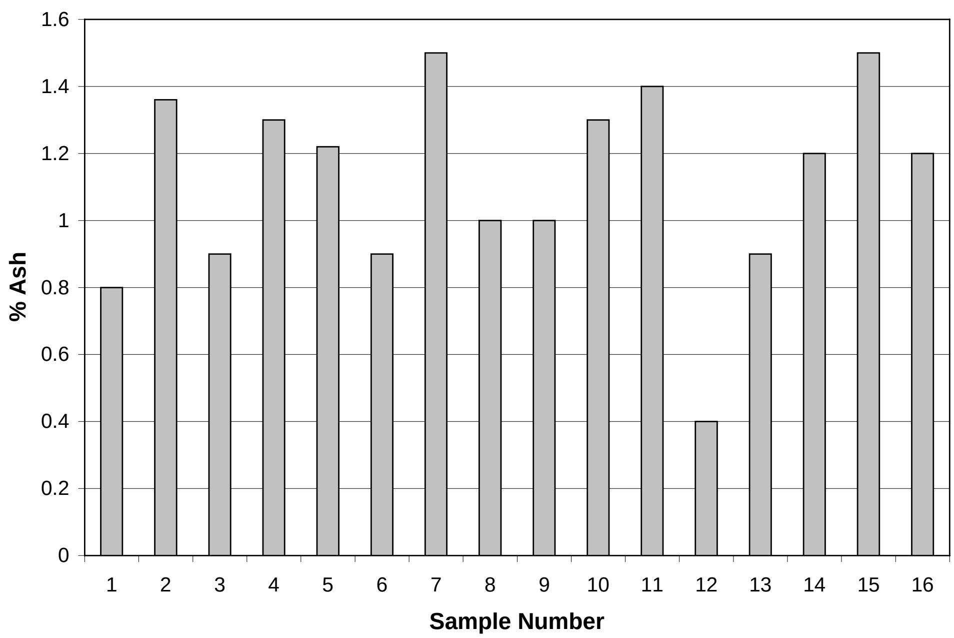

Figure B-7 - Ash Content Values for PCR Mixed Color Samples

The ash content had a range from 0.4 to 1.5%. Earlier results showed that the ash content could be brought below 1% with proper filtration. Therefore, it is proposed to limit the ash content to 1% to ensure good cleaning and filtering procedures.

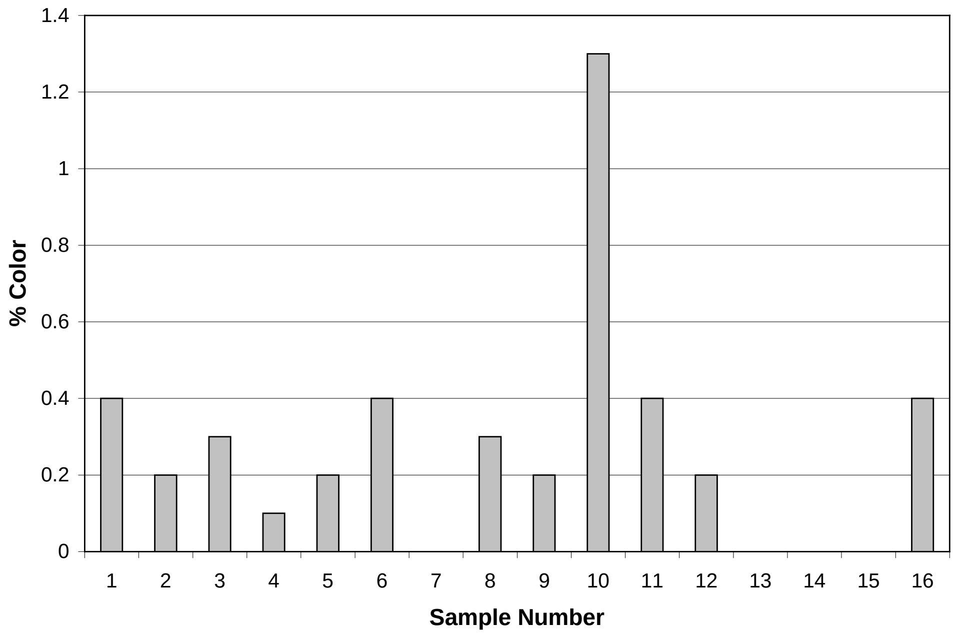

Figure B-8 - Color Content Values for PCR Mixed Color Samples

The % Color results show that there is just a small amount of color present except for sample 10. This particular sample was black in color, so one might assume that the 1.3% was carbon black. The color is not as important as the ash because it is generally in small amounts and does not affect the properties of the recycled, as long as it stays below a few percent.

B.3.2.7 Percentage Polypropylene

The other impurity measured was polypropylene. The results are shown in Figure B-9. The polypropylene content varied from 0.8 to 6.3 % Samples 5 and 7 were not tested). Obviously, some suppliers are better at sorting it out than others. There is also a natural variability based on the number of PP caps that are in the bales of crushed bottles. If the results generated on samples prepared with polypropylene are valid for production lines, then a level of around 5% in the final pipe blend should be acceptable. This means that, as far as polypropylene is concerned, a mixed color resin with 10% could be used in a 50:50 blend. It is believed that the polypropylene content should be limited to 10% in the recycled resin.

B.3.2.8 15% NCTL

The notched constant tensile load stress crack test results are shown in Figure B-10. These results show a range of values from 4.5 to 14.8 hrs. These all fall below the AASHTO requirement of 24 hours. The test is sensitive to the rate of crack growth from an intentional defect (a razor blade cut). It has been shown that the value depends on a variety of PE properties including density, average molecular weight, molecular weight distribution, catalyst type, catalyst activation temperature, and additives. The PI has been performing this test on a variety of polyethylene resins for nearly 20 years and believes there is no way to predict this property, so it needs to be measured if one is interested in a materials inherent resistance to cracking.

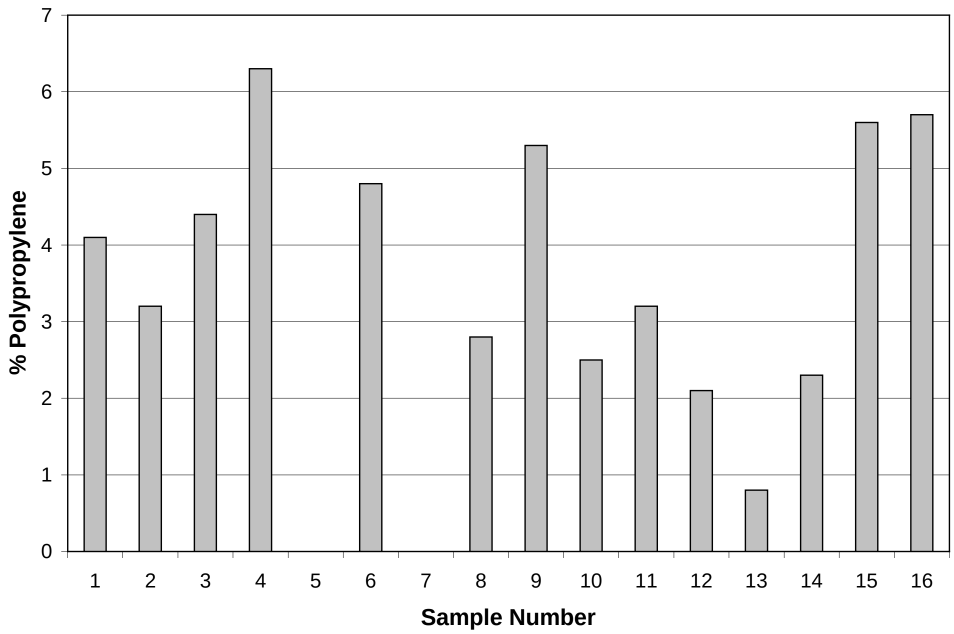

Figure B-9 - % Polypropylene Values for PCR Mixed Color Samples

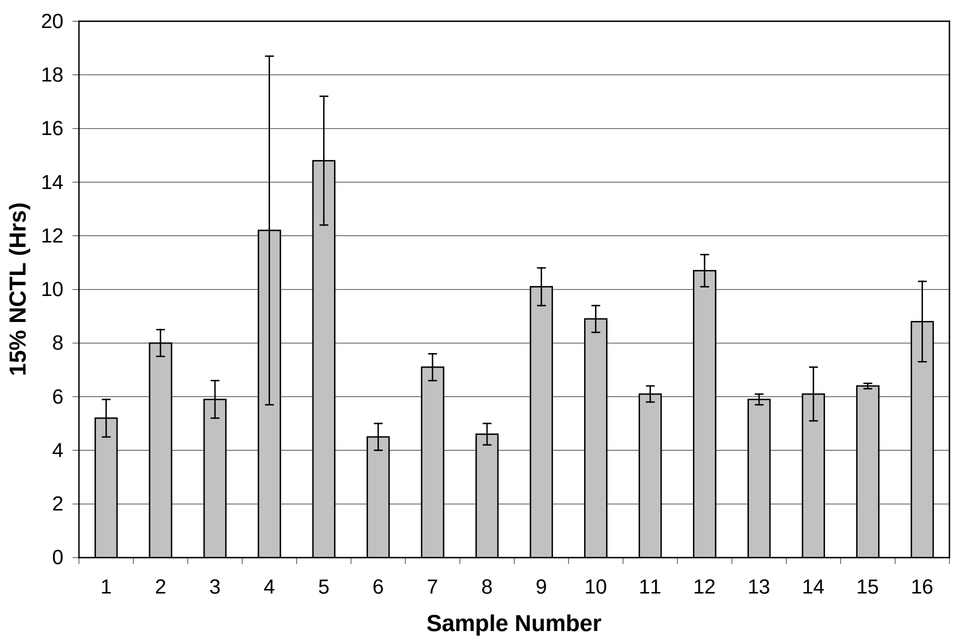

Figure B-10 - 15% NCTL Stress Crack Values for PCR Mixed Color Samples

B.3.2.9 BAM Stress Crack Test

Although the BAM stress crack test has been around for over 15 years, it has never been standardized. Its use has been dictated by a particular problem or application. Therefore, it is still a test in development. The test went through a number of changes during this study in attempts to make it more useful for recycled containing materials. When it was first used to evaluate recycled resins, it was found that the failure times were very short at 80°C in 5% Igepal CA-720 under an applied stress of 580 psi. These had been as close to standard conditions as there was.

An effort was made to determine other appropriate test conditions for recycled resins. Several test temperatures, several environments and a couple of applied stresses were investigated. The results are shown in Table B-4.

Table B-4 - The BAM Test Results on Recycled Resins

Recycled Resin	Test Temp. (°C)	Applied Stress (psi)	Environment	Failure Time (hrs)
MCR1	80	580	5% CA-720	3.2 ± 1.8 2.6 ± 0.6 2.7 ± 0.9
MCRG	50	600	10% CO-630	117 ± 49
	60 60	580 800	Water Water	>115 14.5 ± 1.7 17.3 ± 2.1
	70	580	Water	27.5 ± 13.7
	80 80	580 580	5% CA-720 Water	3.5 ± 1.5 7.4 ± 1.5
MCR3	80	580	Water	9.9 ± 2.9 15.5 ± 4.5 14.5 ± 5.1
MCRG2	80	580	Water	10.7 ± 2.4
Supplier 4 MCR	80	580	Water	34.8 ± 9.3
Supplier 5 MCR	80	580	Water	26.4 ± 4.6
Supplier 6 MCR	80	580	Water	33.6 ± 9.7

The results showed that at a temperature of 80°C in D.I. Water under 580 psi of load, the average failure times will be from a few hours to over 30 hours. More tests are needed to establish a minimum value for recycled resins.

B.3.2.10 OIT and OITemp

The OIT values for the mixed color samples are shown in Figure B-11. Notice that the OIT values were all between 9 and 15 minutes, except for Sample 1, which was 39 minutes. This value was verified, but it seems to be an anomaly, as far as the recycled bottle market is concerned. These OIT values indicate that there is some kind of stabilizer present, which may be a simple shelf-life stabilizer or a process stabilizer.

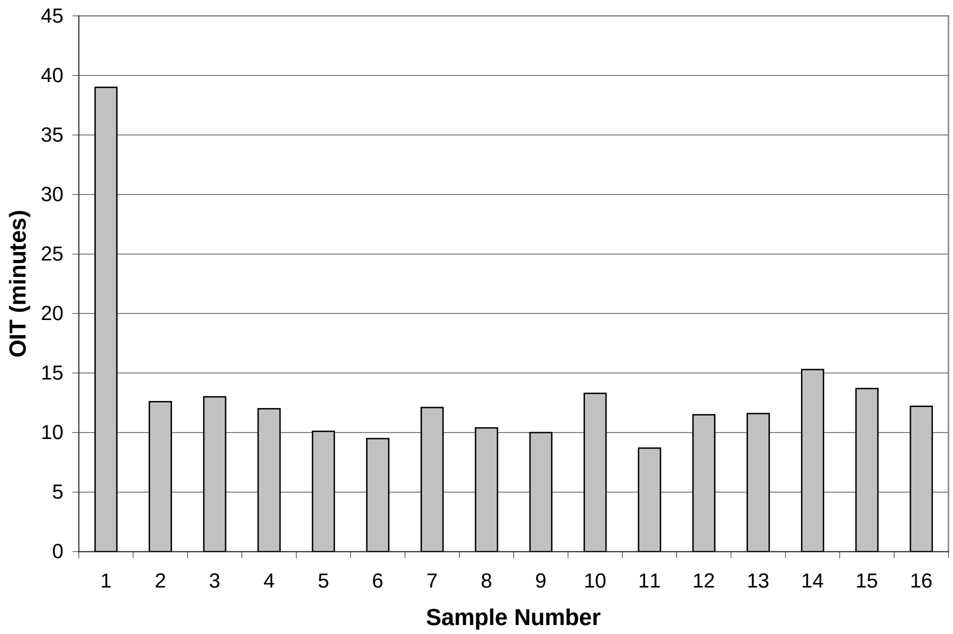

Figure B-11 - OIT Values for PCR Mixed Color Samples

The OITemp values are shown in Figure B-12 and were between 234 and 249°C. This test was not performed on every sample. There has been discussions and controversy over the meaning of both the OIT and the OITemp tests. The results have also been misunderstood and misinterpreted.

The OIT test measures the oxidation resistance of a polyethylene at 200°C and 100% oxygen. The result is totally unrelated to service conditions. Therefore, the magnitude of the value by itself provides very little information. Different stabilizers react to the OIT test in different ways. Some produce high values and others do not register at all. The test is useful for QC/QA if the additive package stays constant because the value does relate to the concentration.

The same thing can be said for the OITemp. The temperature of the onset of oxidation should increase with increasing additive concentration. As far as correlation between the two tests, Figure B-13 shows the correlation between the two tests on 31 data points, including 8 PPI certified corrugated pipe resins, 21 recycled resins and 2 commercial geomembranes.

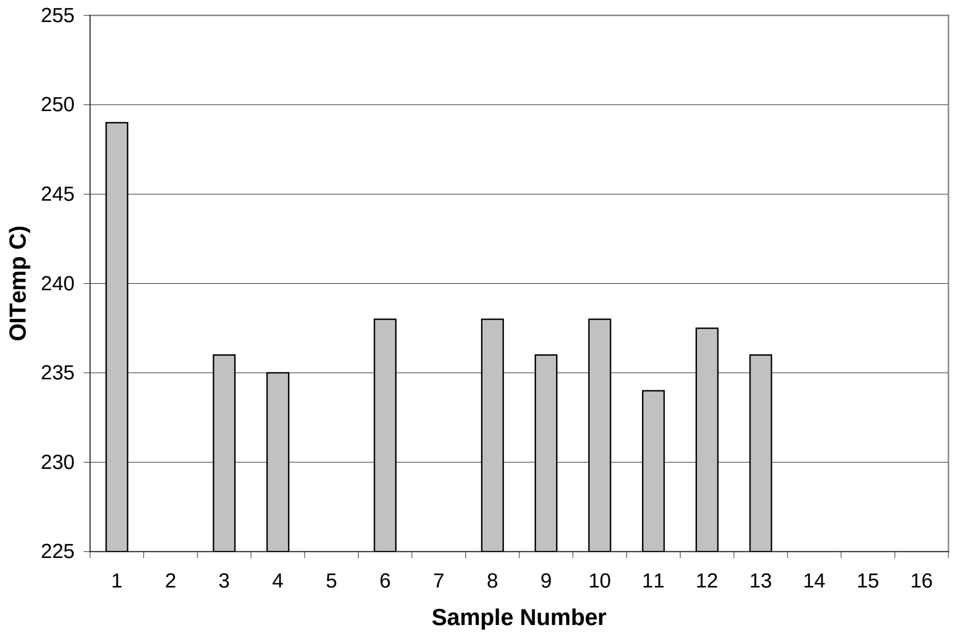

Figure B-12 - OITemp Values for PCR Mixed Color Samples

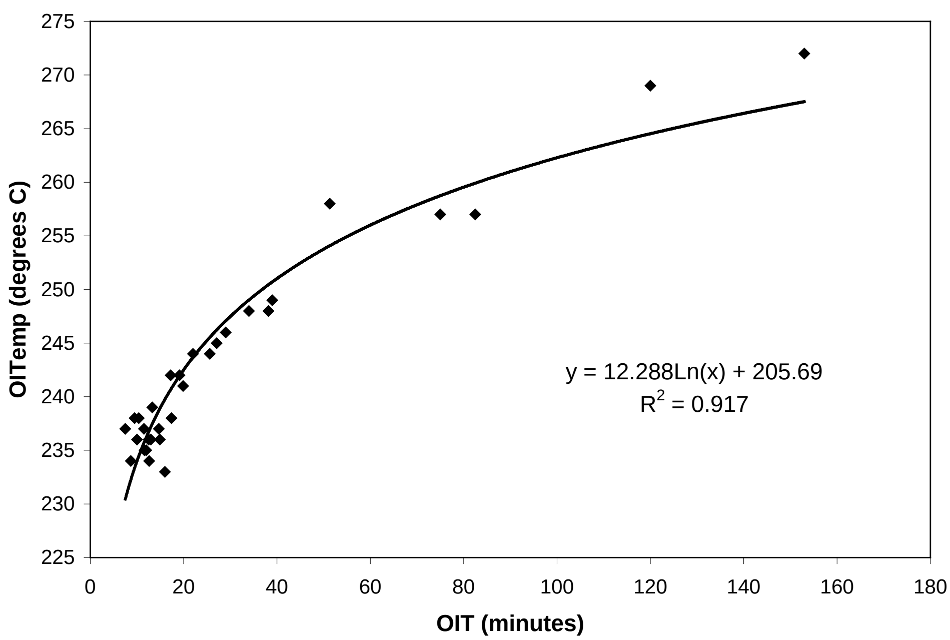

Figure B-13 - Correlation Between OIT and OITemp

These data clearly show that the relationship between the OIT and OITemp is logarithmic, but the correlation is poorer at lower OIT times. Figure B-14 shows the results from limiting the data to those results with an OIT of 40 Minutes or less, since this is where most of the data are.

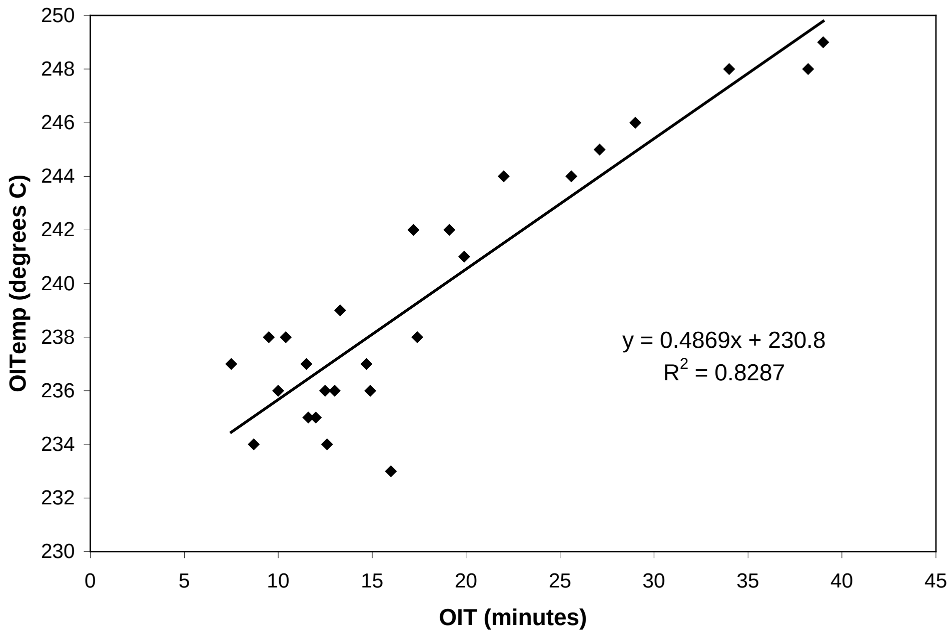

Figure B-14 - Correlation Between OIT and OITemp for OIT Values Below 40 min.

This plot shows that the relationship is generally linear at lower OIT, but its not precise enough to allow a direct correlation. Interestingly, these results show a zero OIT value to be around 231°C for OITemp. ASTM D3350, where the OITemp test is described, requires a value greater than 220°C to ensure a stabilized polyethylene. These results suggests that an unstabilized PE will have a OITemp value greater than 220°C.

In case there was some bias caused by all the recycled resins tested, another set of 45 data points were looked at from the Pennsylvania Deep Burial Study. These were from a 20 year old buried pipe with the same additive package. The correlation is shown in Figure B-15.

These results should settle the controversy. Since the relationship appears to be logarithmic, there will always be a large change in the OIT value for a given change in the OITemp value. That means the OIT test is more sensitive and can distinguish materials better. Additionally, the OIT test is likely to be more sensitive to long-term antioxidants, while the OITemp is better suited to evaluated process stabilizers. For these reasons, the OIT test will be used in the recommended specifications for the use of recycled resins.

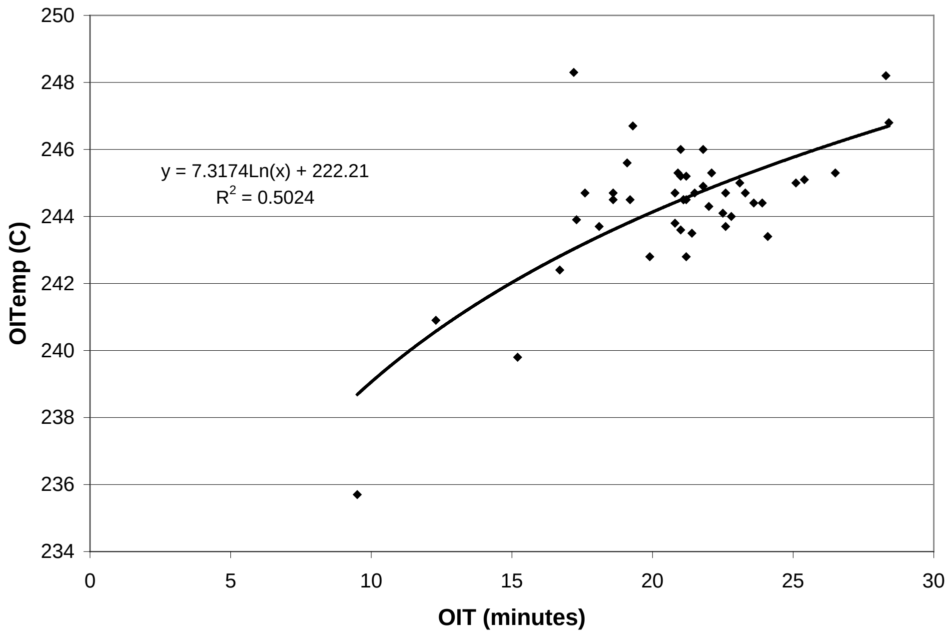

Figure B-15 - Correlation Between OIT and OITemp of
Data from the Pennsylvania Deep Burial Study

B.4 THE EFFECTS OF CONTAMINATION

The types of foreign matter that may be found in post-consumer recycled HDPE include labels, paper, cardboard, dirt, aluminum foil, adhesives, and other polymers like PP (from caps), EVOH (barrier layers), PET or PVC. There is also a new plastic called poly(lactic acid) (PLA), which is derived from corn and is biodegradable. The recycled HDPE may be contaminated with other grades of PE, like LDPE which could affect the cracking resistance. Finally, there may be milk and detergent residue, which produce smoke and odors during processing.

The foreign particulate matter can be removed during the washing step at the recycler and filtered out during extrusion by either the recycler or pipe manufacturer. However, the recyclers who produce reprocessed HDPE are more capable of this because some of them already melt filter to 100-120 mesh while the pipe manufacturers generally filter at a mesh size of 80 or below.

Polypropylene (PP) comes from bottle closures (caps) and is found in mixed color reprocessed HDPE at levels as high as 10-12%. When processed, the PP will blend in with sufficient mixing, or be melted and spread out in the final part. This could affect the behavior of the pipe, especially the stress crack resistance. The HDPE milk bottle resin contains no PP because the caps are made from LDPE. In fact, the recycled natural homopolymer (milk bottle) is much cleaner than the mixed color.

The effects of contamination have been investigated three ways. First, samples containing a known size and percentage of angular sand were prepared to see how the sand affected properties such as tensile elongation and stress crack resistance. These results will offer some guidance concerning how much filtration to specify.

Secondly, two samples containing mixed color regrind (MCRG) were prepared at three levels of filtration.

And finally, samples containing different amounts of polypropylene were prepared and evaluated.

B.4.1 The Effects of Particulates

B.4.1.1 Preparation of Sand Samples

Angular "playground" sand was obtained and sifted with both a 100 mesh and a 120 mesh screen. About 100g of sand passing the 100 mesh but retained by the 120 mesh was obtained. About 50 grams of sand was added to 1950 g of Virgin Resin 1 (VR1) and extruded 3 times to obtain a resin containing 2.5% sand. The temperatures of the die, and other two heating zones were 177 °C (350 °F), while the feed zone was set at 115 °C (240 °F). The screw speed was set at 200 rpm which produced a feed rate of about 16 lbs per hour. The residence time in the barrel was less than 45 seconds. The resulting 0.25 in. rod was passed then cooled and pellitized.

The 2.5% masterbatch was diluted with additional VR1 to produces samples of about 1.6, 0.8, 0.4, and 0.2% sand. The actual values measured by ash analysis on duplicate samples were 1.61, 0.79, 0.41, and 0.25 respectively.

B.4.1.2 The Effect of Sand on Strain-at-Break

The sand sample pellets were compression molded into a 7 in. x 7 in. x 0.06 in. plaque according to ASTM D4703. The pellets were heated to 160°C, pressed quickly to 2500 psi, allowed to relax for 5 minutes, then cooled at 15°C/min to 50°C. The resulting plaque provided samples for both the tensile test and the BAM stress crack test.

The tensile properties of the plaques were measured according to ASTM D638 with the use of a Type IV dumbbell. The rate of extension was 2 in./min and the elongation was calculated from the cross head travel. The results on five replicates are shown in Table B-5.

The effect of sand was best observed in the strain-at-break values. These have been plotted in Figure B-16.

Notice that even 0.25% of sand of this size has a dramatic effect of the strain-at-break. This supports a requirement of melt filtration at 120 mesh and shows that break strain can be used to evaluated the effects of melt filtration.

Table B-5 - Tensile Properties of VR1 Samples Containing Sand

Sample	Yield Stress (psi)	Yield Strain (%)	Break Stress (psi)	Break Strain (%)
0% Sand	3627 ± 85	17.4 ± 0.5	2882 ± 303	468 ± 28
0.25% Sand	3803 ± 45	17.4 ± 1.1	2262 ± 108	144 ± 44
0.41% Sand	3805 ± 79	17.2 ± 1.6	2245 ± 75	114 ± 62
0.79% Sand	3771 ± 41	16.6 ± 0.9	2078 ± 128	85.6 ± 32
1.61% Sand	3794 ± 73	17.6 ± 1.1	2182 ± 61	68.8 ± 25

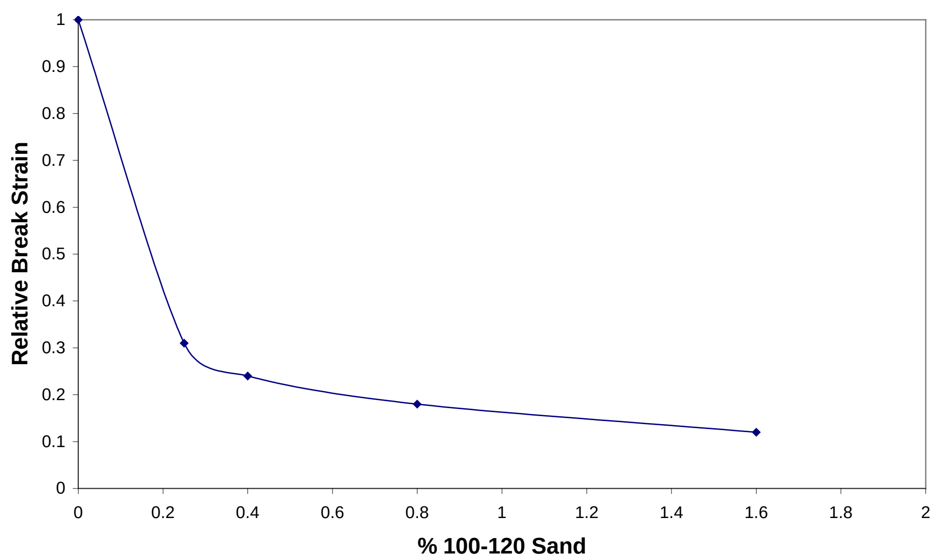

Figure B-16 - The Effect of Sand on the Break Strain of Virgin Resin 1 (VR1)

B.4.1.3 The Effect of Sand on Stress Crack Resistance

This was determined on the same set of samples with the use of an unnotched stress crack test commonly referred to as the BAM test. Samples, 6 in. x ½ in. x 0.06 in. were supported in a surfactant solution (5% CA-720) at 80°C under an applied stress of 4 MPa (580 psi). A stress crack is produced at locations of defects. If there are no particulates present, the samples may fail at an edge where the stamping die has deformed the plastic during sample preparation.

The results of the BAM test at 80°C are shown in Table B-6.

Table B-6 - BAM Stress Crack Test Results on VR1 Samples Containing Sand

Sample	Failure Time (Hrs)
0% Sand	88.1 ± 16
0.25% Sand	54.5 ± 7
0.41 % Sand	38.8 ± 11
0.79 % Sand	43.2 ± 19
1.61% Sand	24.0 ± 9

These data are plotted in Figure B-17.

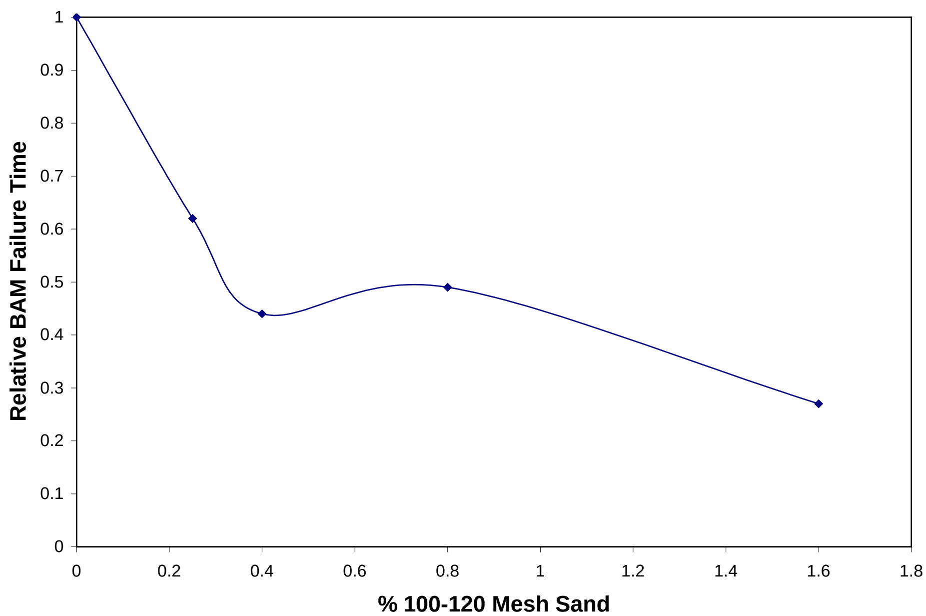

Figure B-17 - Effect of Sand on BAM Stress Crack Resistance

These results also show that particulates of this size can compromise the long-term cracking resistance of pipe.

B.4.2 The Effects of Melt Filtration

B.4.2.1 Sample Preparation

Two types of samples were prepared for this study. The first was 100% mixed color regrind (MCRG) and the second was 50% MCRG + 50% MDPE. Each of these was melt filtered at three different levels. It should also be mentioned that the two sample sets were made with two different batches of mixed color regrind HDPE.

The 100% MCRG was blended without filtration, and also melt filtered at 100 and 150 mesh.

The 50/50 MCRG/MDPE samples were melt filtered at 40, 100, and 150 mesh. The filtration at 40 mesh was to help the material process better by removing larger particles that would cause the melt strand to break.

The filter screen sizes can be expressed as opening size. The values are dependent on the wire diameter, but typical values are shown in Table B-7.

This table shows that particles from about 5 to 6 mils in diameter are the ones that produced the dramatic changes in break strain and stress cracking with the sand samples. This study will evaluate the effects of melt filtration.

Table B-7 - Tyler Mesh Opening Size

Tyler Mesh Size	Opening (mil)	Opening (microns)
80	8	200
100	6	152
120	5	127
150	4	102

B.4.2.2 The Effect of Melt Filtration on Strain-at-Break

The tensile properties were measured on the two sample types. The % strain-at-break was chosen as the best result to follow the effects of blending. Plots of the effects of melt filtration on both type of samples are shown in Figures B-18 and B-19. Five replicates were tested for the 100% MCRG and 10 were tested for the 50/50 MCRG/MDPE.

Both sets of results indicate that melt filtration dramatically improves the properties of recycled HDPE and blends containing HDPE. Notice in Figure B-19 that the scatter in results gets smaller with better melt filtration. This is important data because tensile specimens always fail at a defect. The plotted results clearly show that melt filtration removes defects. The coefficients of variation (standard deviation/mean x 100) for the three results were 69, 30, and 10% with increasing mesh size. A 10% COV is acceptable, even for virgin resins. This is a direct result of fewer larger particles in the samples.

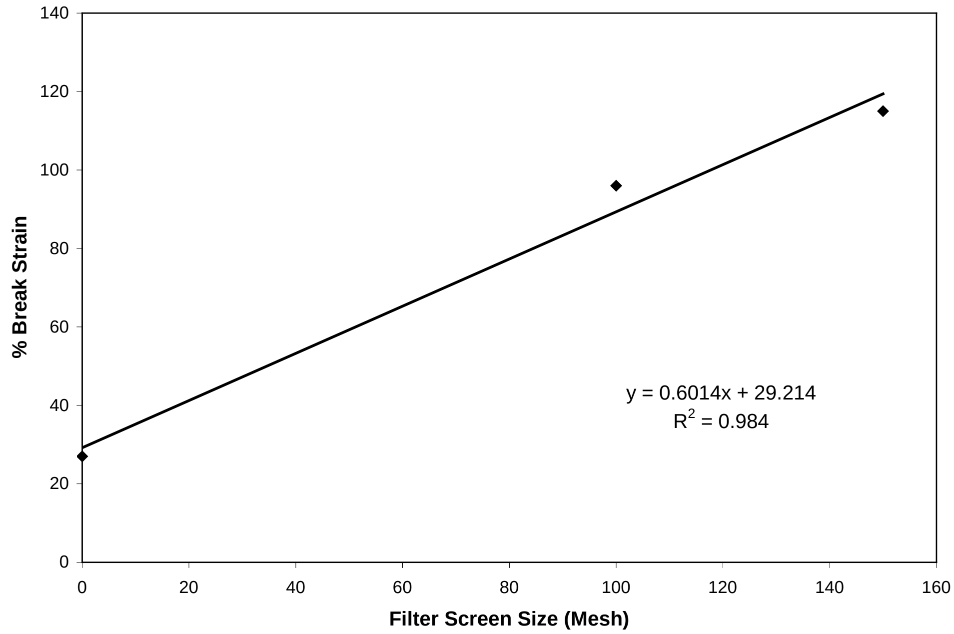

Figure B-18 - The Effect of Melt Filtration on the % Break Strain of 100% Mixed Color Regrind (MCRG)

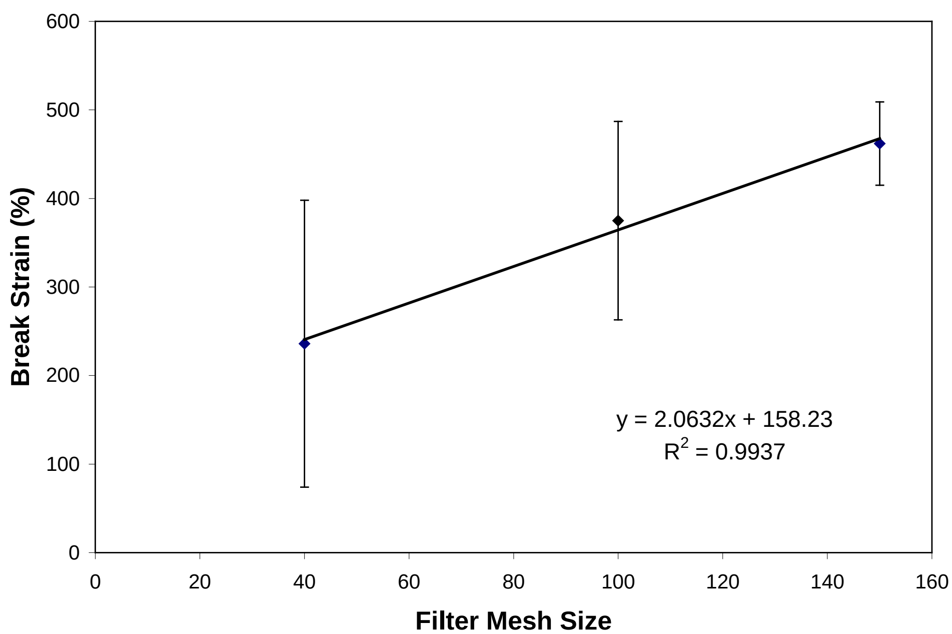

Figure B-19 - The Effect of Melt Filtration on the % Break Strain of 50/50 MCRG/MDPE

B.4.2.3 The Effect of Melt Filtration on the BAM Stress Crack Resistance

The BAM stress crack test is usually performed at 80°C in a surfactant (Igepal CA720) on a specimen without a notch. It is basically a flaw detector. The results were similar to the tensile results. Longer failure times were associated with higher mesh size. The results for both sets of results are shown in Figures B-20 and B-21. The tests run on the 100% MCRG were at a temperature of 70°C.

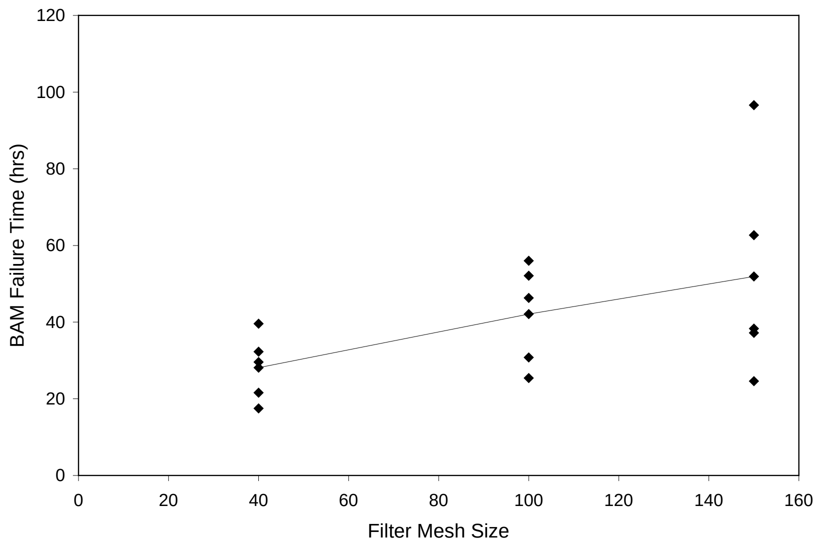

Figure B-20 - The Effect of Melt Filtration on the BAM Failure Time of 100% MCRG at 70°C

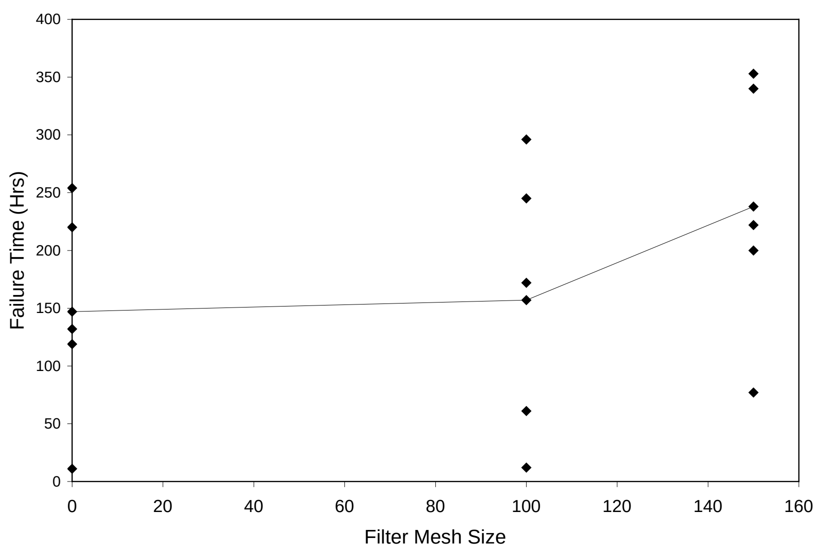

Figure B-21 - The Effect of Melt Filtration on the BAM Failure Time of 50/50 MCRG/MDPE at 80°C

Notice that the scatter is very large in this test and that the differences in average failure time are not great.

One of the advantages of the BAM test is that the fractured surface can be examined to see where the crack started. Examples are shown in Figures B-22 and B-23.

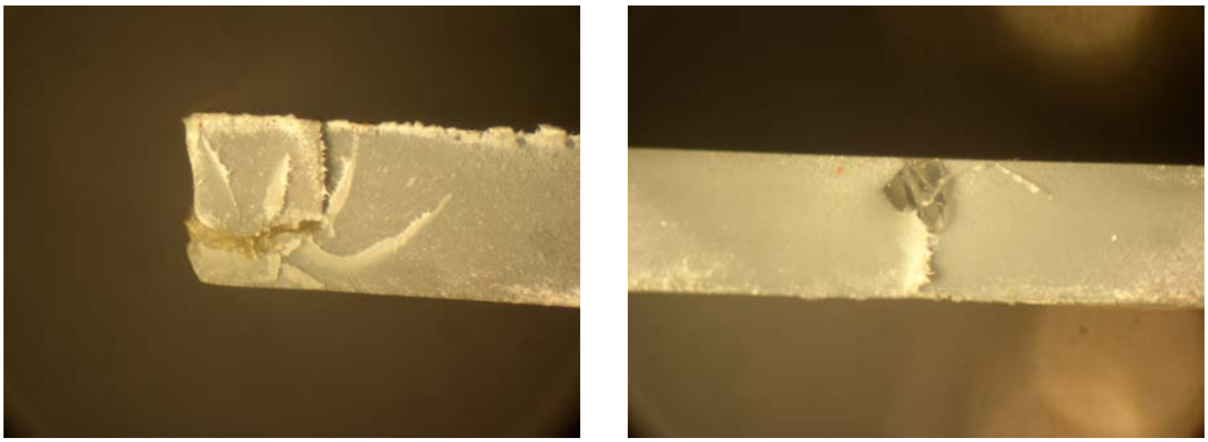

Figure B-22 - BAM Test Fracture Surfaces for Failure Times of 11 and 133 Hours (Unfiltered)

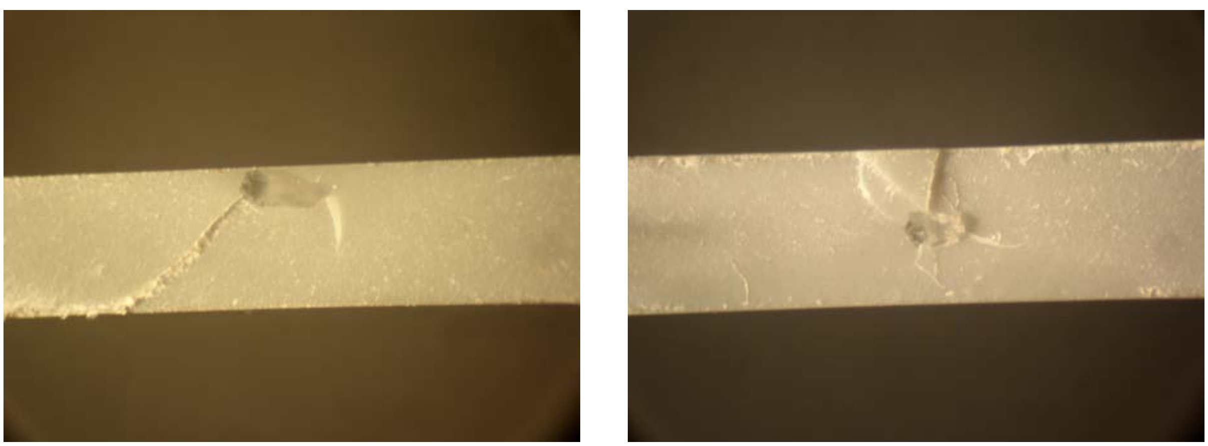

Figure B-23 - BAM Test Fracture Surfaces for Failure Times of 12 and 172 Hours (100 Mesh)

The clear, rubbery material was identified as Silicone Rubber by FTIR analysis. The IR results are shown in Figure B-24.

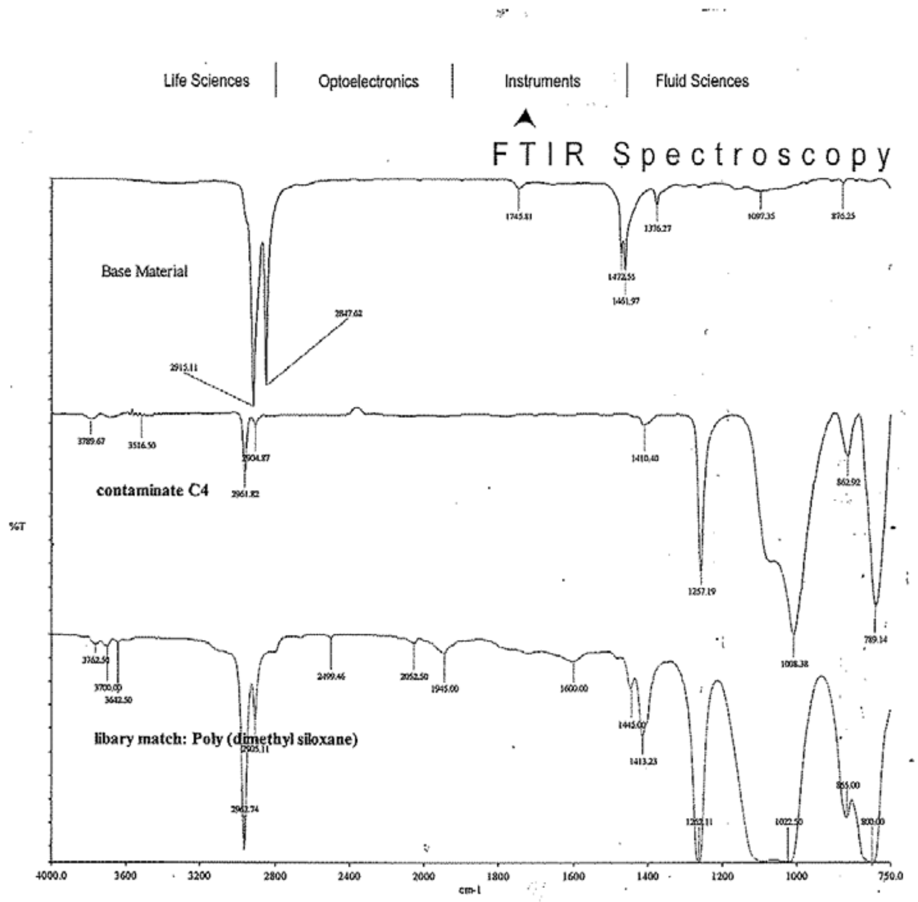

Figure B-24 - FTIR Spectra for HDPE (top), the Rubbery Contaminant (middle), and the Best Library Match, Silicone Rubber

Four different rubbery particles were tested and they all looked the same. It is not clear where the silicone rubber came from, but it is known that the rubber bladder found in the caps of some wide-mouth bottles is made from silicone rubber. Rubber has been seen in ketchup, mustard, jelly, and dessert topping bottles. Unfortunately, the rubber particles are so flexible that they pass through the filter screens. However, it is believed that the particles can be broken up by the screens, so better filtration should produce smaller particles. If this is combined with improvements in stress crack resistance, then it is believed that the effect of this contaminant can be minimized.

B.4.3 The Effects of Polypropylene

Polypropylene (PP) is a contaminant in post-consumer mixed color regrind and reprocessed resins that comes from the colored bottle closures. The recyclers report PP at levels up to 10-12% by weight. Therefore, it is important to know its effect on the properties of HDPE.

There are two obvious ways to measure %PP. The first is with the use of Fourier Transform Infrared (FTIR) Spectroscopy. FTIR is an analytical technique that takes advantage of the fact that different combination of atoms absorb IR radiation at different frequencies. The technique produces a chemical fingerprint of absorption bands of different intensities and at different frequencies. This can be used as a quantitative tool because the height of a particular band is directly related to its concentration, assuming the specimen thickness (path length) is a constant. With a blend of polyethylene and polypropylene, one can ratio two peaks, each specific to one of the polymers. The ratio of these peaks will be linearly related to the relative concentrations, up to a certain limit that can be determined experimentally. This technique works well for natural resins but becomes more difficult in the presence of colorants, particularly carbon black. These absorb IR radiation and can affect the peak heights and shift the linear portion of a calibration curve.

The other way is with the use of differential scanning calorimetry (DSC). A DSC measures thermodynamic transitions, like melting or decomposition. This is the method of choice during this study and details of the method wre presented in Appendix A.

B.4.3.1 Preparation of Polypropylene Samples

The polypropylene used in this study was from a container that produced an identical DSC scan to a PP Detergent Bottle Closure. The container was first ground, then added to virgin resin 3 (VR3) as a dry blend containing 2, 5, and 10% polypropylene. The three dry blends were then mixed on the twin screw extruder affixed with 150 Mesh screens. The material was passed through the extruder three times under standard conditions.

B.4.3.2 The Effect of PP on Density

Since the density of polypropylene is around 0.90 g/cm^3, one would expect the density to decrease as the % PP increased. That is exactly what was observed, as seen in Figure B-25. This plot shows that the resulting density of a blend will be affected by the %PP. This fact, along with the presence of both organic and inorganic fillers makes the density measurement on blends unreliable.

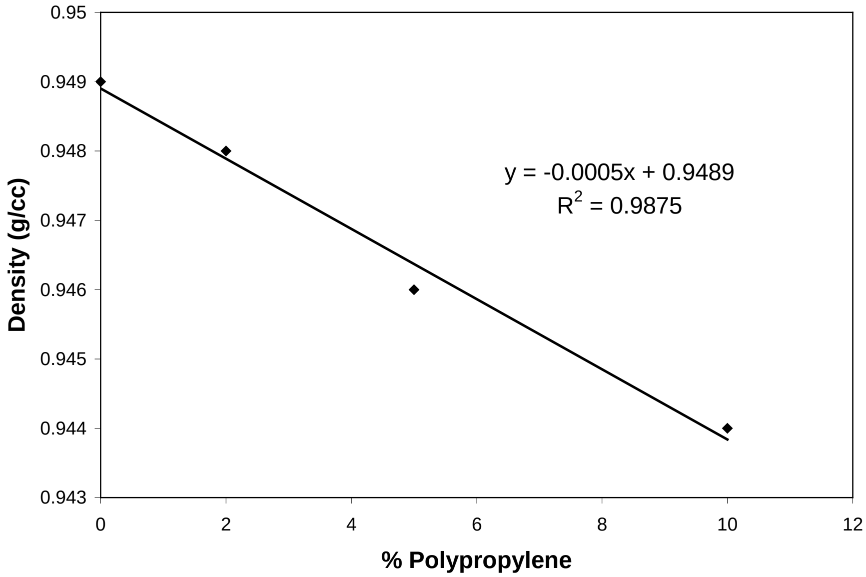

Figure B-25 - The Effect of %PP on Density

B.4.3.3 The Effect of % PP on Melt Index

Since the PP is an injection molding grade, one would expect the melt index (MI) to increase with added PP (Figure B-26).

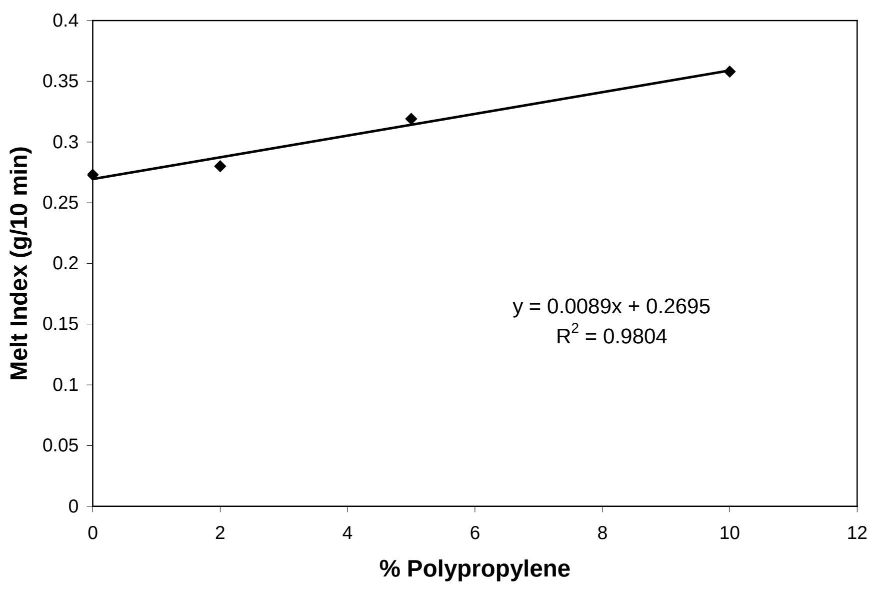

Figure B-26 - The Effect of %PP on Melt Index

B.4.3.4 The Effect of %PP on Strain-at-Break

PP acts as a contaminant, which reduces the break strain (Figure B-27).

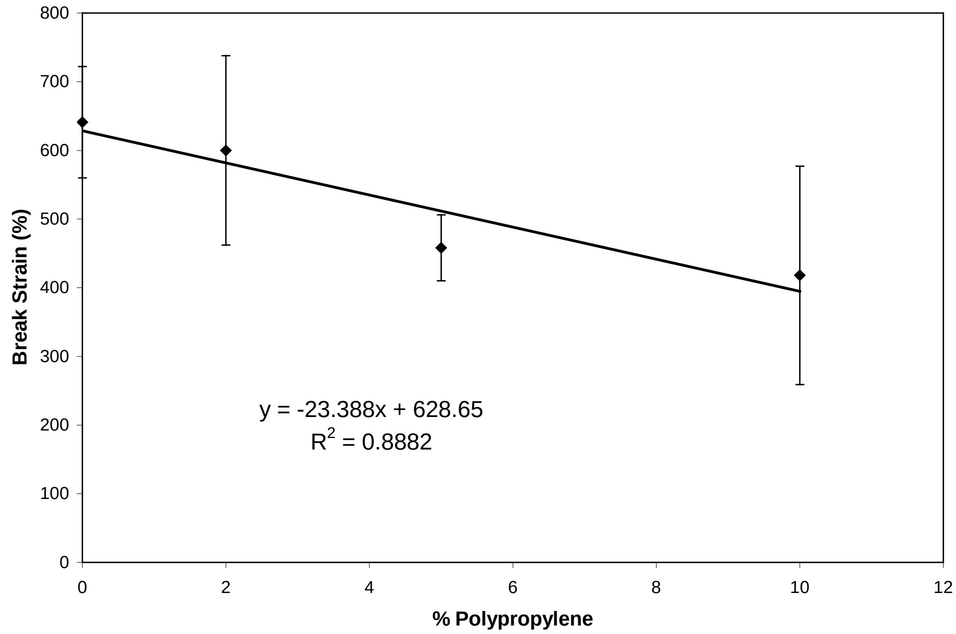

Figure B-27 - The Effect of %PP on Break Strain

B.4.3.5 The Effect of %PP on Stress Crack Resistance

The results of this test are quite interesting. The results of the NCLS test on the samples with 2, 5, and 10% PP are shown in Figure B-28. Notice that the failure times actually increased for the 2% and 5% samples, then became shorter than the baseline at 10% PP. This result was not expected and it was believe that it reflected the difference in yield stress caused by the addition of PP. So, the test was repeated under a load of 15% of the yield stress (reduced stress). These results are found in Figure B-29 and are identical to the previous ones. The only conclusion is that at small amounts, well blended PP can increase the stress crack resistance by about 10%.

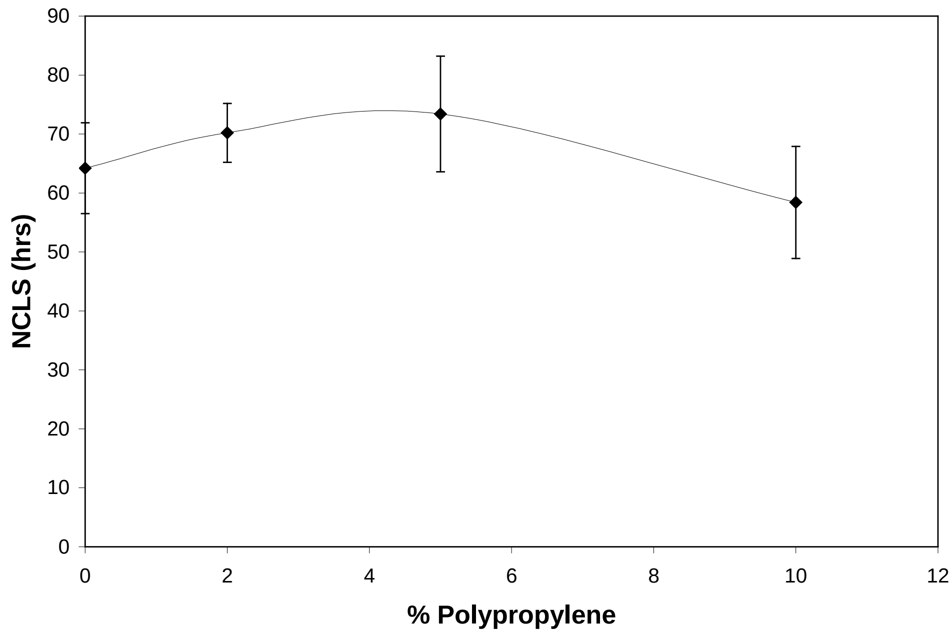

Figure B-28 - The Effect of %PP on the NCLS Failure Time

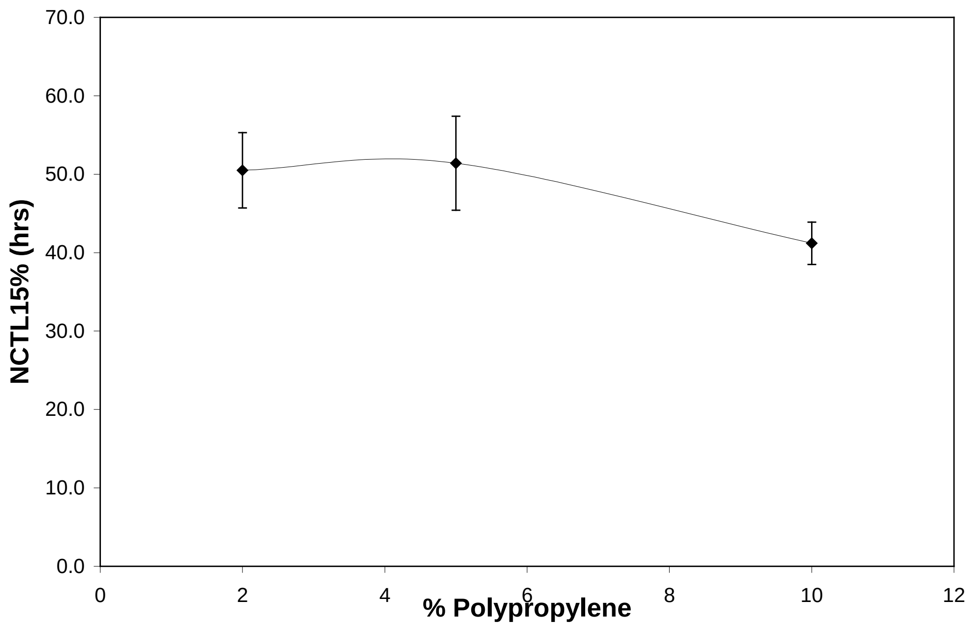

Figure B-29 - The Effect of %PP on the NCTL Failure Time

B.5 Test Reports For Post-Industrial Recycled Polyethylene Resin Samples

TEST RESULTS
Recycled HDPE Classification
PIR Reprocessed HDPE
Supplier 5

Material: Plaque from blended resin (MB 1X)
Sample: Post Industrial Reprocessed HD

Date: 8-May-07
TRI Log #: F7601

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.969	0.97	0.97			0.970	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.32	0.32				0.32	
21.6 kg (g/10 min)	26.4	26				26.2	
Ratio						101	
Composition							
% Volatiles*	0.24					0.24	
% Color	0.29	0.25	0.31			0.28	0.025
% Ash	3.20	4.18				3.69	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3260	3178	3180	3027	3069	3143	72
Break Strain (%)	535	692	608	633	672	628	35
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	96.1	105.0	113.0	114.0	90.9	104	4
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	18.2					18.2	

TEST RESULTS
Recycled MDPE Classification
PIR MDPE Regrind
Supplier 9

Material: Plaque from blended resin (MB 3X)
Sample: Post Industrial Medium Density Regrind

Date: 2-Oct-07
TRI Log #: F7601

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.942	0.942	0.942			0.942	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.63	0.69				0.66	
21.6 kg (g/10 min)	30.3	30.2				30.3	
Ratio						46	
Composition							
% Volatiles*							
% Color	1.05	1.05	1.05			1.05	0.000
% Ash	0.10	0.00				0.05	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	2679	2606	2646	2635	2588	2631	17
Break Strain (%)	756	755	646	694	461	662	45
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	>800	>800	>800	>800	>800	>800	
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	61.4					61.4	

TEST RESULTS
Recycled HDPE Classification
PIR Reprocessed LLDPE
Supplier 5

Material: Plaque from blended resin (MB 1X)
Sample: Post Industrial Reprocessed LD

Date: 8-May-07
TRI Log #: F7601

	Test Replicate Number						
PARAMETER	1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.952	0.952	0.952			0.952	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.82	0.78				0.80	
21.6 kg (g/10 min)	26.8	27.9				27.4	
Ratio						34	
Composition							
% Volatiles*	0.18					0.18	
% Color	0.16	0.14	0.15			0.15	0.008
% Ash	3.76	3.74				3.75	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	1680	1645	1744	1671	1692	1686	42
Break Strain (%)	723	734	761	729	687	727	14
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	>300	>300	>300	>300	>300	>300	
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	6.3					6.3	

B.6 Test Reports for Post – Consumer Recycled Natural HDPE Resins

TEST RESULTS
Recycled HDPE Classification
PCR Natural Reprocessed
Supplier 2

Material: Plaque from HDPE Pellets (MB 1X)
Sample: Natural Reprocessed

Date: 13-Dec-06
TRI Log #: E2274-78-03

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.957	0.957	0.957			0.957	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.63	0.65				0.64	
21.6 kg (g/10 min)	53.6	54.5				54.1	
Ratio						86	
Composition							
% Volatiles*	0.07	0.06				0.06	
% Ash	0.2	0.12				0.16	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	4400	4434	4413	4381	4270	4380	22
Break Strain (%)	264	161	274	139	190	206	59
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	3.3	3.2	3.3	4.1	3.3	3.4	0.4
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	14.9					14.9	
Induction Temp (deg C) (ASTM D3350)	236					236	

TEST RESULTS
Recycled HDPE Blend
Post Consumer Natural Reprocessed
Supplier 2, Sample 2

Material: Plaque from blended resin (MB 3X @ 150 Mesh) | Date: 22-Oct-07
Sample: Nat Repro | TRI Log #: F7601

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.960	0.96	0.96			0.960	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.80	0.82				0.81	
21.6 kg (g/10 min)	62.5	61.2				61.9	
Ratio						76	
Composition							
% Ash	0.02	0.03	0.10			0.05	0.036
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	4396	4539	4495	4492	4522	4489	50
Break Strain (%)	169	127	245	354	249	229	78
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	1.8	1.8	1.8	1.8	1.8	1.8	0
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	9.1					9.1	

TEST RESULTS
Recycled HDPE Classification
PCR Natural Reprocessed
Supplier 3

Material: Plaque from HDPE Pellets (MB 0X)
Sample: Natural Reprocessed HDPE

Date: 14-Dec-06
TRI Log #: E2274-80-03

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.954	0.955	0.956			0.955	0.001
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.57	0.56				0.57	
21.6 kg (g/10 min)	55	54				54.5	
Ratio						96	
Composition							
% Volatiles*	0.06					0.06	
% Ash	0.09	0.07	0.07			0.08	0.009
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	4300	4333	4362	4333	4194	4304	14
Break Strain (%)	81	18	130	32	116	75	50
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	4.0	3.8	4.0	3.7	3.5	3.8	0.1
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	27.1					27.1	
Induction Temp (deg C) (ASTM D3350)	245					245	

TEST RESULTS
Recycled HDPE Classification
Resin Type: Natural Regrind
Supplier 6

Material: Plaque from HDPE Pellets (MB 3X)
Sample: Clean Regrind Flake

Date: 19-Jan-07
TRI Log #: E2274-97-09

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.957	0.957	0.958			0.957	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.71	0.65				0.68	
21.6 kg (g/10 min)	61.4	61.9				61.7	
Ratio						91	
Composition							
% Volatiles							
% Ash	0.13	0.14	0.15			0.14	0.008
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	4410	4452	4507	4431	4382	4436	32
Break Strain (%)	231	29	137	20	175	118	53
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	5.8	5.8	5.8	5.3	5.8	5.7	0.2
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	14.7					14.7	
Induction Temp (deg C) (ASTM D3350)	237	238				238	

TEST RESULTS
Recycled HDPE Classification
PCR Natural Reprocessed
Prepared by TRI

Material: Plaque from blended resin (MB 2X @ 100 Mesh)
Sample: 100% Natural Repro

Date: 13-Feb-07
TRI Log #: F7601

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.960	0.96	0.96			0.960	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.71	0.87				0.79	
21.6 kg (g/10 min)	52.7	59.3				56.0	
Ratio						71	
Composition							
% Volatiles	0.08					0.08	
% Color/Ash	0.06	0.05				0.06	
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	4543	4507	4515	4536	4514	4523	14
Break Strain (%)	70	194	496	638	427	365	206
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	2.0	2.0	2.0	2.1	1.7	2.0	0.1
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)							

TEST RESULTS
Recycled HDPE Classification
Resin Type: Natural
Milk Bottle

Material: Plaque from milk bottle
Sample:

Date: 31-Jan-07
TRI Log #:

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.958	0.958	0.958			0.958	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.74	0.74				0.74	
21.6 kg (g/10 min)	53.9	57.7				55.8	
Ratio						75	
Composition							
% Volatiles	0.04					0.04	
% Ash	0.05	0.04	0.03			0.04	0.008
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	4342	4307	4338	4315	4278	4316	13
Break Strain (%)	10	124	22	172	244	114	63
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	6.9	4.3	5.7	4.9	5.1	5.4	0.6
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)						23	

B.7 Test Reports for Post–Consumer Mixed Color HDPE Resins

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Regrind
Supplier 1

Material: Plaque from blended regrind (MB 2X)
Sample: HDPE Mixed Color Regrind

Date: 11-Dec-06
TRI Log #: E2274-75-08

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.948	0.947	0.949			0.948	0.001
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.36	0.37				0.37	
21.6 kg (g/10 min)	34.5	32.6				33.6	
Ratio						93	
Composition							
% Volatiles*	0.24					0.24	
% Color	0.33	0.52	0.48			0.44	0.082
% Ash	0.72	0.89				0.81	
% PP	3.7	4.6				4.1	
* on as-received chips							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3162	3352	3419	3408	3293	3327	29
Break Strain (%)	8	13	37	41	29	26	12
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	4.9	5.0	6.5	5.1	4.7	5.2	0.7
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	39.0					39.0	
Induction Temp (deg C) (ASTM D3350)	249					249	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Regrind
Supplier 1, Sample 2

Material: Plaque from blended resin (MB 3X @ 100 Mesh)
Sample: HDPE Mixed Color Regrind

Date: 19-Mar-07
TRI Log #: F7601

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.960	0.960	0.960			0.960	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.47	0.49				0.48	
21.6 kg (g/10 min)	39.3	39.9				39.6	
Ratio						83	
Composition							
% Color/Ash	1.58	1.58	1.55			1.57	0.014
% PP	3.2					3.2	
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3486	3493	3443	3417	3366	3441	47
Break Strain (%)	128	223	132	140	166	158	35
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	7.8	8.6	7.2	7.7	8.6	8.0	0.5
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	12.6					12.6	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Regrind
Supplier 2

Material: Plaque from blended regrind (MB 3X)
Sample: HDPE Mixed Color Regrind

Date: 6-Jan-07
TRI Log #: E2274-75-08

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.962	0.962	0.962			0.962	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.63	0.65				0.64	
21.6 kg (g/10 min)	48.0	48.1				48.1	
Ratio						75	
Composition							
% Volatiles*	0.17					0.17	
% Color	0.33	0.26	0.28			0.29	0.029
% Ash	0.91	0.95				0.93	
% PP	5.1	3.8				4.4	
* on as-received chips							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	4055	4026	3960	4034	4112	4037	33
Break Strain (%)	10	24	58	12	32	27	19
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	5.8	6.9	5.3	5.8	5.8	5.9	0.7
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	12.5	13.7				13.0	
Induction Temp (deg C) (ASTM D3350)	235	237				236	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed
Supplier 2

Material: Plaque from HDPE Pellets (MB 1X)
Sample: Mixed Color Reprocessed

Date: 13-Dec-06
TRI Log #: E2274-78-03

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.946	0.946	0.947			0.946	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.56	0.56				0.56	
21.6 kg (g/10 min)	56	59.8				57.9	
Ratio						103	
Composition							
% Volatiles*	0.24	0.24				0.24	
% Color	0.13	0.13	0.13			0.13	0.000
% Ash	1.29	1.28				1.29	
% PP	6.8	5.8				6.3	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3662	3705	3797	3763	3733	3732	38
Break Strain (%)	31	10	30	15	12	20	8
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	10.1	8.6	23	10.1	9	12.2	6.5
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	11.2	12.4				12.0	
Induction Temp (deg C) (ASTM D3350)	234	236				235	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed + Supplier 2

Material: Plaque from HDPE Pellets (MB 1X)
Sample: Mixed Color + HMW Reprocessed

Date: 23-Jan-06
TRI Log #: E2274-78-03

	Test Replicate Number						
PARAMETER	1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.957	0.957	0.958			0.957	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.514	0.536				0.53	
21.6 kg (g/10 min)	47.8	49				48.4	
Ratio						91	
Composition							
% Volatiles*							
% Color+Ash	1.37	1.38	1.35			1.37	0.012
% PP							
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3500	3623	3500	3744	3641	3602	100
Break Strain (%)	16	15	10	58	14	23	22
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	13.9	18.1	15.9	12.3	13.9	14.8	2.4
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	10.1					10.1	
Induction Temp (deg C) (ASTM D3350)							

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Regrind
Supplier 3

Material: Plaque from blended regrind (MB 2X)
Sample: HDPE Mixed Color Regrind

Date: 22-Jan-07
TRI Log #: E2274-89-08

	Test Replicate Number						
PARAMETER	1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.961	0.961	0.961			0.961	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.57	0.57				0.57	
21.6 kg (g/10 min)	52.4	54.1				53.3	
Ratio						94	
Composition							
% Volatiles*	0.12	0.15				0.14	
% Color	0.42	0.42	0.38			0.41	0.019
% Ash	0.91	0.97				0.94	
% PP	4.0	5.6				4.8	
* on as-received chips							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3986	3980	3959	3987	3920	3966	12
Break Strain (%)	21	19	23	36	34	27	7
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	4.2	5.2	5.2	4.2	3.6	4.5	0.5
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	10.0	9.0				9.5	
Induction Temp (deg C) (ASTM D3350)	237	238				238	

TEST RESULTS
Recycled HDPE Blend
PCR Mixed Color Regrind
Supplier 3, Sample 2

Material: Plaque from blended resin (MB 3X @ 150 Mesh)
Sample: 100% Mixed Color Regrind

Date: 16-Oct-07
TRI Log #: F7601

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.960	0.960	0.960			0.960	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.55	0.49				0.52	
21.6 kg (g/10 min)	50.3	51.2				50.8	
Ratio						97	
Composition							
% Ash	1.45	1.46				1.46	
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3708	3613	3623	3626	3493	3613	69
Break Strain (%)	158	183	215	158	142	171	26
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	7.1	7.9	7.1	7.1	6.3	7.1	0.5
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	12.1					12.1	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed
Supplier 3

Material: Plaque from HDPE Pellets (MB 1X)
Sample: Mixed Color Reprocessed HDPE

Date: 14-Dec-06
TRI Log #: E2274-80-03

PARAMETER	Test Replicate Number 1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.953	0.953	0.951			0.952	0.001
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.45	0.43				0.44	
21.6 kg (g/10 min)	52.8	52.3				52.6	
Ratio						117	
Composition							
% Volatiles*	0.22					0.22	
% Color	0.32	0.33	0.30			0.32	0.012
% Ash	0.99	1.06				1.03	
% PP	2.8					2.8	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3929	3864	3900	3969	3909	3876	50
	3832	3798	3865	3872	3819		
Break Strain (%)	87	89	103	61	120	72	34
	106	18	68	21	44		
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	4.2	5.2	4.2	4.8	4.8	4.6	0.4
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	10.4					10.4	
Induction Temp (deg C) (ASTM D3350)	238					238	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed + Supplier 3

Material: Plaque from HDPE Pellets (MB 1X)
Sample: Mixed Color + HMW Reprocessed HDPE

Date: 14-Dec-06
TRI Log #: E2274-80-03

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.955	0.955	0.956			0.955	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.39	0.37				0.38	
21.6 kg (g/10 min)	46.5	46.4				46.5	
Ratio						122	
Composition							
% Volatiles*	0.52					0.52	
% Color+ Ash	1.26	1.16	1.16			1.19	0.047
% PP	5.3					5.3	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3606	3385	3593	3611	3500	3539	103
Break Strain (%)	10	7	9	8	9	9	1
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	10.9	10.9	9.1	9.7	9.9	10.1	0.7
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	10					10.0	
Induction Temp (deg C) (ASTM D3350)	236					236	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed
Supplier 4

Material: Plaque from blended resin (MB 1X)
Sample: HDPE Mixed Color Reprocessed

Date: 19-Jan-07
TRI Log #: E2274-83-05

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.954	0.955	0.957			0.955	
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.54	0.57				0.56	
21.6 kg (g/10 min)	49	49.8				49.4	
Ratio						88	
Composition							
% Volatiles*	0.21					0.21	
% Color	1.27	1.33	1.32			1.31	0.026
% Ash	1.30	1.29				1.30	
% PP	2.3	2.8				2.5	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3673	3758	3564	3644	3769	3616	93
	3620	3523	3501	3615	3494		
Break Strain (%)	56	129	58	73	51	110	70
	220	248	32	139	93		
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	9.1	9.1	8.3	9.4	8.4	8.9	0.5
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	10.6	16.0				13.3	
Induction Temp (deg C) (ASTM D3350)	240	239				238	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed
Supplier 5

Material: Plaque from blended resin (MB 1X)
Sample: HDPE Mixed Color Reprocessed

Date: 22-Jan-07
TRI Log #: E2274-86-06

	Test Replicate Number						
PARAMETER	1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.956	0.957	0.957			0.957	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.42	0.43				0.43	
21.6 kg (g/10 min)	45.3	41.5				43.4	
Ratio						101	
Composition							
% Volatiles*	0.16					0.16	
% Color	0.49	0.41	0.33			0.41	0.065
% Ash	1.46	1.37				1.42	
% PP	3.2	3.1				3.2	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	4038	4026	4080	4059	3983	3995	54
	3959	3976	3988	3950	3890		
Break Strain (%)	25	16	58	66	45	50	22
	64	83	54	21	69		
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	6.8	6.2	5.5	6.0	6.2	6.1	0.3
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	8.7					8.7	
Induction Temp (deg C) (ASTM D3350)	234	235				234	

TEST RESULTS
Recycled HDPE Classification
(PCR Mixed Color + PIR) Reprocessed
Supplier 5

Material: Plaque from blended resin (MB 1X)
Sample: HDPE Mixed Color + PIR Reprocessed

Date: 22-Jan-07
TRI Log #: E2274-86-06

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.953	0.953	0.953			0.953	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.31	0.31				0.31	
21.6 kg (g/10 min)	24.5	25.1				24.8	
Ratio						80	
Composition							
% Volatiles*	0.15					0.15	
% Color	0.17	0.17	0.14			0.16	0.014
% Ash	0.39	0.42				0.41	
% PP	1.4	2.8				2.1	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3955	4012	4051	4076	4029	4007	53
	3881	4030	3976	4027	4034		
Break Strain (%)	497	230	131	280	274	302	123
	177	205	408	506	314		
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	10.1	10.8	10.4	11.9	10.1	10.7	0.6
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	11.5					11.5	
Induction Temp (deg C) (ASTM D3350)	237	238				237	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed
Supplier 6

Material: Plaque from HDPE Pellets (MB 3X)
Sample: Mixed Color Reprocessed

Date: 19-Jan-07
TRI Log #: E2274-97-09

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.959	0.959	0.959			0.959	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.58	0.59				0.59	
21.6 kg (g/10 min)	50.5	54.6				52.6	
Ratio						89	
Composition							
% Volatiles*	0.24					0.24	
% Color	0.00	0.00	0.00			0.00	0.000
% Ash	0.92	0.9				0.91	
% PP	0.8	0.8				0.8	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3989	3973	3873	3827	3802	3825	61
	3745	3763	3840	3683	3758		
Break Strain (%)	177	178	134	149	136	155	90
	157	199	227	444	284		
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	6.3	5.6	6.0	5.7	5.7	5.9	0.2
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	11.6					11.6	
Induction Temp (deg C) (ASTM D3350)	236	235				236	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed
Supplier 7

Material: Plaque from blended resin (MB 1X)
Sample: HDPE Mixed Color Reprocessed

Date: 7-Mar-07
TRI Log #: E2277-28-05

	Test Replicate Number						
PARAMETER	1	2	3	4	5	Mean	STD
Density (ASTM D 1505)							
Density (g/cm3)	0.947	0.948	0.947			0.947	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.43	0.46				0.45	
21.6 kg (g/10 min)	47.2	47.9				47.6	
Ratio						106	
Composition							
% Volatiles*	0.26					0.26	
% Color	0.00	0.00				0.00	
% Ash	1.17	1.17				1.17	
% PP	2.3					2.3	
*on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3789	3662	3792	3658	3657	3712	62
Break Strain (%)	134	67	165	13	114	99	63
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	6.0	7.1	7.4	5.1	4.9	6.1	1.0
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	15.3					15.3	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed
Supplier 8

Material: Plaque from HDPE Pellets (MB 3X) | Date: 5-Dec-07
Sample: Mixed Color Reprocessed HDPE | TRI Log #: E2299-99-06

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.958	0.958	0.959			0.958	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.31	0.33				0.32	
21.6 kg (g/10 min)	36.1	36.3				36.2	
Ratio						113	
Composition							
% Volatiles*	0.31					0.31	
% Ash	1.45	1.48				1.47	
% PP	5.6	6.1	5.2			5.6	
* on as-received pellets							
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3603	3581	3587	3733	3620	3625	70
Break Strain (%)	97	107	88	131	114	107	18
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	6.3	6.4	6.5	6.6	6.1	6.4	0.1
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	13.7					13.7	

TEST RESULTS
Recycled HDPE Classification
PCR Mixed Color Reprocessed
Prepared by TRI

Material: Plaque from blended resin (MB 3X)
Sample: 100% MCR1

Date: 9-Feb-07
TRI Log #: F7601

PARAMETER	1	2	3	4	5	Mean	STD
	Test Replicate Number						
Density (ASTM D 1505)							
Density (g/cm3)	0.960	0.960	0.960			0.960	0.000
Melt Flow Index (ASTM D 1238)							
2.16 kg (g/10min)	0.53	0.55				0.54	
21.6 kg (g/10 min)	46.9	43.6				45.2	
Ratio						83	
Composition							
% Color/Ash	1.61	1.67	1.39			1.56	0.120
% PP	5.7					5.7	
Tensile Properties (ASTM D 638)							
Yield Strength (psi)	3591	3708	3724	3718	3684	3685	49
Break Strain (%)	80	31	33	18	68	46	24
Environmental Stress Crack Resistance (ASTM D5397 @ 15% of Yield)							
Failure Time (hours)	10.9	10.4	7.8	7.0	8.1	8.8	1.5
Oxidative Stability (ASTM D 3895)							
Induction Time (min) (ASTM D3895)	12.2					12.2	

B.8 Recycled Resin Suppliers

ABC Polymers, Inc. – PC, PI
Ponce de Leon Ave
Stone Mountain, GA 30083
Tel: (770) 938-8336
Fax: (770) 934-8621
www.abcpolymers.com

Able Plastics - PI
3700 Roswell Road
Marietta, GA 30062
Tel: 770/565-1522
Fax: 770/973-8499
Email: info@ableplastics.com
Web: www.ableplasics.com

American Polymers Corporation –PC,PI
231 Springside Drive
Akron, OH 44333
Tel: 330/666-6048
Fax: 330/668-4829
Web: www.americanpolymerscope.com

Arrotin Plastics Materials, Inc.-
PC,PI
San Bernardino, CA 92408
Phone 909-799-1387
Fax 909-799-1307
alex@arrotin.com
Web: www.arrotin.com

Atlantic Polymers & Colors, Inc.
Off-Spec
P.O. Box 908
Rye, NH 03870
Tel: 603/436-8333
Tel: 603/434-0512
Fax: 603/436-8655
Web: atlanticpoly@comcast.net

Avangard Industries, LTD
3000 Brittmoore, Rd.
Houston, TX 77043
Main (713) 895-9697
Fax (713) 895-9698
www.avangard.com

Bamberger Polymers - Wide-Spec
Two Jericho Plaza
Jericho, NY 11753
Tel: 800/888-8959
Tel: 516/622-3600
Fax: 516/622-3610
Web: www.bambergerpolymers.com

Bata Plastics – PC, PI
1251 100^{th} St. SW
Byron Center MI 49315
Tel: 616/878-5480
Fax: 616/878-5485
Web: www.bataplastics.com

Bay Polymer Corp. - PI
44530 Grimmer Blvd.
Fremont, CA 94566
Tel: 510/490-1791
Fax: 510/490-5914
Web: www.baypolymer.com

Berou International, Inc.
9701, Colbert
Anjou (Quebec)
H1J 1Z Canada
Tel: 514-353-8954
Web: www.berouinternational.com

Blue Ridge Plastics, LLC
Donald W. Grigg
Box 1243
206 Warehouse Street
Eden, NC 27289
Tel: 919/522-2011
Fax: 336/623-4432
Web: www.blueridgeplastics.com

Capco Polymer Industries - PI
Columbiana, OH
Tel: 888/482-4686
Web: www.capcopolymers.com

Carolina Plastics, Inc.
105 Warehouse Road
Seneca, SC 29672
Tel: 864/985-1501
Fax: 864/985-1543
Email: billy@carolinaplastics.com
Web: www.carolinaplastics.com

C.C. Reprocessing, Inc. - PI
627 Rockmart Road
Villa Rica, GA 30180
Tel: 770/459-9001
Fax: 770/459-0504
Web: www.ccreprocessing.com

Clean Tech, Inc.
500 N. Dunham Street
Dundee, MI 48131
Tel: 734-529-2475
Fax: 734-529-5766 Contact: Karl Hatopp
Email: khatopp@plastipak.com

Commercial Plastics Recycling, Inc.
Ben Benvenuti
Tel: 813/248-4212
Fax: 813/248-5634
Benb@cprinc.net
www.cprinc.net

Custom Polymers, Inc. - PI
700 Tuckaseegee Road
Charlotte, NC 28208
Tel: 704/332-6070
Tel: 866/717-0716
Fax: 704/372-1606
Web: www.custompolymers.com

Denton Plastics - PI
1811 NE San Rafael
St. Portland, OR 97230
Tel: 800/959-9945
Tel: 503/257-9945
Fax: 503/252-5319
Web: www.denplas.com

Domino Plastics - PI
26 Hulse Road
Seauket, NY 11733
Tel: 631/642-1995
Fax: 631/642-1771
Email: domino@domplas.com
Web: www.domplas.com

Entropex
1271 Lougar Ave.
SARNIA, Ontario
N7S 5N5 Canada
Tel: (519) 332-0430
Web: www.entropex.com

Envision Plastics - PC
606B Walters St.
Reidsville, NC 27320
Tel: 336/342-4749
Fax: 336/342-9841
Web: www.envisionplastics.com

Gar Plastics, Inc. - PI
240 North Birdsey St.
Columbus, WI 53925
Tel: 920/623-5775
Fax: 920/623-9755
Web: www.garplastic.com

Go Polymers - PI
Tel: 425/557-0600
Fax: 425/557-0670
Email: info@go-polymers.com
Web: www.go-polymers.com

Graham Recycling Company, L.P. –PC
Robin Marshall
2401 Pleasant Valley Rd
York, PA 17402-9600
Tel: 717/849-8650
Fax: 717/845-4448
Web: www.grahampackaging.com

Hoehn Plastics, Inc. - PI
Highway 165 North
County Road 925 South
Poseyville, Indiana 47633
Phone: (812) 874-2612
Fax: (812) 874-2861
www.hoehnplastics.com

JLM Plastics Corp. - PI
1012 Collins Street
Joliet, IL 60432
Tel: 815/722-0066
Fax: 815/722-0535
Email: jimplastics@sbcglobal.net
Web: www.jlmplastics.com

KW Plastics – PC, PI
Sanders Road
Troy, AL 36081
Tel: 800/633-8744
Tel: 334/566-1563
Fax: 334/670-0036
Web: www.kwplastics.com

Manner Resins - PI
105 Eastern Ave., Suite 103
Annapolis, MD 21403
Tel: 410/571-0570
Fax: 410/571-0320
Email: tsyre@mannerresins.com
Web: www.mannerresin.com

Merlin Plastics - PI
616-58th Ave. SE
Calgary, Alberta
Canada T2H 0P8
Tel: 403/259-6637
Fax: 403/259-6679
Web: www.merlinplastics.com

New Life Plastic Recycling Inc.
129 W. Trade Street
Burlington, NC 27215
Phone: (336) 222-7775
Fax: (336) 222-6935
Web: www.newlifeplastics.com

Plast-Ex International Inc.
15 Armthorpe Road
Brampton, Ontario
L6T 5M4 Canada
Tel: 905/793-3600
Fax: 905/793-2500
Email: postoffice@plast-ex.com

Plastic Revolutions – PC, PI
103 W. Harrison Street
Reidsville, NC 27320
Tel: 888/532-9274
Tel: 336/349-2800
Web: www.plasticrevolutions.com

Polychem Products Ltd.
725, rue Gaudette
St-Jean-sur-Richelieu, Quebec
Canada J3B 7S7
Tel: 450-348-7392
Web: www.polychemproducts.com

Polymer Marketing Inc. - PI
Tel: 770/952-1147
Fax: 770/951-2474
Email: Sales@polymark.com

Polyreps –PC, PI
2501 Ashcraft Ave.
Monroe, NC 28110
Tel: 704/238-9949
Fax: 704/238-8518
Email: info@polyreps.com

PolyTrade, Inc. - PI
1033 Providence Rd.
Whitinsville, MA 01588
Tel: 508-234-7400
Fax: 508-234-2208
www.polytrade.com

RBW Technologies, Inc. – PI?
433 Hartmann Road
Evans City, PA 16033
Tel: 724/452-8440
Fax: 724/452-0810
Email: sales@rbw.com

Rainier Plastics, Inc. - PI
1101 Ledwich Ave.
PO Box 9125
Yakima, WA 98909
Tel: 509/248-1473
Fax: 509/453-7385
Email: info@rainierplastics.com

ReactionPolymers Inc. – PI
3984 South 500 West
Salt Lake City, Utah 84123
Phone: (801) 281-0512
Mobile: (801) 641-6544
Fax: (801) 281-0511
Email: sales@reactionpolymers.com
Web: www.reactionpolymers.com

Recycling Solutions Inc. - PI
PO Box 46224
Chicago, IL 60646
Tel: 773/794-9300
Fax: 773/685-0559
Web: www.apexq.com

ReGen Polymers, LLC - PI
10756 Hi Tech Drive
Whitmore Lake, MI 48189
Tel: 734.449.9020
Fax: 734.449.8350
www.regenpolymers.com

Reliable Resins Company - PI
11016 Portobelo Drive
San Diego, CA 92124
Tel: 858/277-6844
Fax: 858/277-6848
Web: www.reliable-resins.com

Shuman Plastics - PI
35 Neoga Street
Buffalo, NY 14043
Tel: 716/685-2121
Fax: 716/685-3236
Email: info@shuman-plastics.com

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Ed Barker
1579 S. Folsomville Rd.
Boonville, IN 47601
812-897-4840
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Solplast Inc.
1501 des Futailles
Montreal, Qc
Canada H1N 3P1
514-254-8525
www.solplastinc.com

Talco Plastics, Inc.
3270 E 70th Street
Long Beach , CA 90805
Tel: 951-531-2000
Fax: 951-531-2059
Contact: William O'Grady
Email: billo@talcoplastics.com

Trademark Plastics Corp.
One Washington Park, Suite 1200
Newark, NJ 07102
Tel: 908-925-5900
Web: www.trademarkplasticscorp.com

Triad Plastics, Inc. - PI
600 East Crescent Ave
Upper Saddle River, NJ 07458
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Fax: 201/825-0999
Email: info@triadplasticsinc.com