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Studies on the Mechanical and Sorption Properties of *Anacardium* Occidentale L. Exudate and Polypropylene Blends

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ABSTRACT
This research work employed the use of purified cashew gum (PCG) as a blender for polypropylene (PP). The blended samples were subjected to tensile, hardness, impact and sorption tests. There was a general decrease in tensile strength and percentage elongation with increasing PCG composition. An improvement in Young's Modulus was recorded at PCG concentration of 10%. Also, the hardness properties of the samples increased to a maximum value of 61 HRF corresponding to PCG concentration of 40%. A general decrease in impact strength with increasing PCG concentration was observed. Sorption test results indicate that blended samples with PCG compositions in the range of 50% and above gave very high values of degree of swelling (DS). Thus blended samples in this composition range are more prone to hydrolytic degradation as a result of swelling behaviour in aqueous media. The blending of PP with PCG has resulted in lowering the production cost of the blended samples. It also induced biodegradation in these plastics thus serving as a means of controlling environmental pollution.
Keywords: Purified Cashew Gum, Polypropylene, Blended samples

1. Introduction

Polymers are increasingly used in many applications in view of their good strength and low densities. Blending of polymers for property improvement or for economic advantage has gained considerable importance in the field of polymer science in the last decade (George *et al*., 1986). Polymer blending provides a powerful route to engineering new properties in materials using available polymers. From Polymer blending it is possible to produce a range of materials with properties that are superior to that of each individual component polymers (Rhoo *et al*., 1997; Oh and Kim, 1999; Pielichowski, 1999; Stephen *et al*., 2000; Tang and Liau, 2000; Pielichowski and Hamerton, 2000).

In recent time, research is focusing increasingly on the development of polymers that combine the desired functionality during use and rapid degradation after disposal as a viable alternative to conventional nondegradable polymers, mostly for applications in which long degradation times are undesirable. Biodegradable polymers fit this context perfectly, since they degrade rapidly and contain nontoxic end products which have low permanence in the environment and are completely metabolized by soil microorganisms (Scott and Gillead, 1995).

The biopolymer of choice in this work is *Anacardium occidentale* exudate, popularly called Cashew tree gum. Cashew gum (CG) is an exudate polysaccharide from *Anacardium occidentale* trees. The plant is native to Brazil and grows in many tropical and sub-tropical countries. Major cashew growing areas in Nigeria are most states in the South-East and South-West (Ezeagu, 2002).

The gum has been studied widely for various pharmaceutical applications as it is inexpensive, non-toxic, biodegradable, and possesses appropriate physicochemical characteristics (Gyedu-Akoto *et al*. 2008 and Kumar *et al*., 2009).

In this present work, Cashew tree gum which would be subjected to chemical purification will be used as a blender on polypropylene, PP of laboratory grade as the base matrix for blending. These blends would be prepared through melt mixing technique using the two-roll mill maintained at appropriate processing conditions. This would be followed by compression molding of the blended samples using a mould engraved with standard sample dimensions. The mechanical properties as well as the chemical resistance of the polymer blends produced would be investigated.

2. Materials and Equipment

A list of all the materials and equipment used in this research work are listed in tables 1and 2 respectively.

3. Procedure for Blend Formulation

Each PP and PCG powder was thoroughly mixed together in the two-roll mill to give blends of various compositions. 30g of plastic/gum blend composition was formulated. The various compositions of the blend samples of PP/PCG were obtained as shown in table 3.

The results of 100: 0 for PP/PCG homopolymers was used as control. The blending technique employed is melt blending. A laboratory-scale two-roll mill was employed for blend preparations. The samples were blended with the front roll maintained at a temperature of 190 ^{o}C while the rear roll was at temperature of 160 ^{o}C.

The polypropylene homopolymers were initially placed on the front roll for 3 min to facilitate processing. Then the roll mill was started and the PCG powder added intermittently a little at a time. The milling was continued for 5 minutes. Occasionally, the molten blend was scraped out from the roll, wrapped several times and milled back to the roll. After 5 min of milling, the molten blend was scraped out and cut into specimens of approximately 2 cm × 2 cm in size. These pieces were then put into a grinding mill, and small pellet-sized samples were obtained. The blended sample pellets were subjected to compression moulding at standard processing conditions.

The blended samples were characterized by various analytical methods such as: absorption tests, tensile tests, impact tests and hardness tests.

3.1 Compression Moulding

The polymer blends were introduced into an aluminum mould sprayed with a mould release agent and wrapped with aluminum foil (for easy removal of the specimen after molding). This mold was designed to accommodate samples with dimensions according to ASTM standard.

The compression molding was carried out on a Carver Laboratory Press equipped with temperature controllers. The temperature was set at 190^{o}C at a pressure of 8.5 Tons for a determined period of 8 minutes. The molded samples were then separated from the mold and labeled appropriately.

4. Blend Charaterization

4.1 Determination of the Density of Blended Samples

The dimensions (length, width and thickness) of the blended polymer samples were accurately measured with the aid of venier calipers while their masses were measured using an electronic weighing balance. The above measurements were carried out in order to obtain the density of each blend composition. It is also aimed at determining the effect of PCG on the density of PP. The densities of the blended samples were then compared with that of the control sample.

4.2 Absorption Test

Water absorption tests for the blend samples were investigated according to ASTM D0570 standard. The polymer blends were suspended in 200 ml of distilled water at room temperature in desiccators for a total period of 7 days with readings taken after every 24 hours. After the required amount of time the samples were removed and gently dried using a filter paper to remove water adhering to its surface. The degree of swelling (DS) was calculated using the following equation:

$$DS = \left(\frac{m_2 - m_1}{m_1}\right) X\ 100 \qquad (1)$$

Similarly, the weight loss (WL) was calculated using the equation:

$$WL = \left(\frac{m_1 - m_2}{m_1}\right) X\ 100 \qquad (2)$$

Where, m_1 is the initial mass of sample blend while m_2 is the final weight of the sample.

4.3 Mechanical tests

4.3.1 Tensile Test

The determinations of the tensile strength of the blended samples were carried out according to ASTM D3039 standard. Sample dimensions of: 100 mm × 10 mm × 4 mm length, breadth and thickness were used. The experiments were conducted on a universal loading machine type Hounsfield Tensometer of maximum capacity 20.00 KN at room temperature. A guage length of 30 mm was used. Tensile analysis of the samples was accomplished using a tensile load of 2.00 KN at moderate strain rate until the point of failure. From the tensile analysis, force and elongation values were recorded. Young´s modulus, ultimate tensile strength and percentage elongation were calculated from the resultant stress-strain curves.

4.3.2 Hardness Test

Hardness values of the blended samples were determined according to the standard ASTM D2240-89 using Indentec Hardness Testing Machine. Rockwell test (F-Scale) with 1/16 inch (steel ball) indentor was used. The minor load used was 10 kg while the major load used was 60 kg with an exposure time of 10 seconds. The hardness test on each of the blended samples was conducted at three different points distributed over the test piece to obtain mean values.

4.3.3 Charpy Impact Test

Charpy impact test analysis for the samples was conducted according to ASTM 370 standard using a Charpy Impact Testing Machine of hammer capacity 15 J and 25 J respectively. In this analysis the 15 J capacity

hammer was employed to determine the fracture energy of each sample. The impact strength of each sample was calculated using the expression:

$$\text{Impact Strength} = \frac{Fracture\ Energy\ Required}{Area\ of\ the\ Sample} \quad (3)$$

5. RESULTS AND DISCUSSIONS

5.1 Density Analysis of Sample Blends

Sample densities of PP/PCG blends are graphically illustrated in fig. 1.

From figure 1, it is observed that there is a gradual increase in the density of the sample blends with increase in PCG composition. Thus the blend sample with composition 20%PP/80%PCG has the highest density value of 0.998 g/cm^3 while the control sample with composition 100%PP/0%PCG has the lowest density value of 0.830 g/cm^3. This result implies that the blending of PP with PCG results in a slight increase in the density of the blended sample. This increase is observed to be more pronounced at higher concentrations of PCG compared to lower concentrations.

5.2 Water sorption Test on Blended Samples

The results of water sorption tests conducted on PP/PCG blend samples are given in figures 2.

During water sorption analysis, the tested samples were observed to be less dense than water. The percentage values given in the above figures are all DS (degree of swelling) values. The PP control sample was resistant to water as evident from the zero DS percentage value. The hydrophobic nature of this sample at ambient conditions makes it impermeable to water. From figure 2 the degree of swelling (DS) gradually increases from a value of 0.00 % for the control sample to a maximum value of 32.63 % for sample 302 (20%PP/80%PCG) which has the highest composition of PCG. The increase in DS values with increase in the percentage of PCG is due to the high affinity of PCG for water. Hence PP blended with PCG will be more susceptible to hydrolytic degradation.

5.3 Mechanical tests

5.3.1 Tensile Test

The results of tensile tests conducted on PP/PCG blends and the control sample are shown in figures 3, 4 and 5 below. All the samples used for analysis are of the same dimension with:

Area (A_o): 10 mm × 4 mm = 40 mm^2 = 4.00 × 10^{-5} m^2

Gauge Length (L_o): 30 mm.

The results of the tensile test analysis of the blended samples are summarized in figure 6.

From figures 3 to 5 and figure 6, it is observed that the tensile strength and percentage elongation of the samples generally decrease in a regular manner with increase in the composition of PCG in the samples. The general decrease in tensile properties with increase in PCG concentration can be attributed to lower intermolecular interactions between PCG and PP. For Young's modulus, the sample with composition 90%PP/10%PCG has a very high value compared to the other samples. This result indicates that the incorporation of a small amount of about 10% of PCG into PP increases its modulus. It also indicates that further increase in PCG composition above 10% results to a decrease in Young's modulus of the PP sample blends. The percentage elongation is also observed to decrease with increase in PCG concentration. This decrease can be attributed to the low toughness of PCG at ambient conditions as a result of high brittleness.

5.3.2 Hardness Test Analysis of Blended Samples

The results of hardness tests conducted on PP/PCG sample blends are shown in figure 7. These results were obtained using the Hardness Rockwell F – scale (HRF). From Figure 7 it can be seen that the hardness values gradually increase with increase in composition as shown in 100%PP/0%PCG whose value is 48.000, to a maximum value of 61.00 for sample with composition 60%PP/40%PCG after which it drastically decreases to a minimum value of 1.70 indicated by the sample with composition 20%PP/80%PCG. Thus, the blending of PP with PCG at concentrations of 10% to 40 % result to improvements in the hardness properties of PP. Very high concentrations of PCG in PP/PCG blends reduce the hardness of PP.

5.3.3 Charpy Impact Test Analysis of Blended Samples

The impact test results for PP/PCG blended samples are given in figure 8. The results of impact test analysis on PP/PCG blended samples indicate a linear decrease in impact strength with increase in the PCG composition with the control sample having the highest impact strength value of 23863.63 Jm^{-2} while the sample with the highest PCG concentration has the lowest value of 4318.18 Jm^{-2}. The low impact strength values of samples with high proportions of PCG can be attributed to the phenomenon of plasticization as the PCG softens the polymer at high concentration values. This gives rise to low toughness of the resulting polymer blend.

6. Conclusion

From this research wok centered on cashew gum and the corresponding blends with polypropylene, the following conclusions can be drawn:

Blending of PP with PCG slightly increases the density of the corresponding blended sample. This gradual increase in density values is an indication that the much appreciated lightness of plastics is preserved when blended with PCG.

The sorption properties of PP/PCG blended samples indicated a gradual increase in DS values with increase in the percentage of PCG in the blended samples. This increase has been attributed to the high affinity of PCG which is a component of the resulting polymer blend to water. Thus the resulting polymer blend is more susceptible to hydrolytic degradation compared to the unblended sample. This implies that hydrolytic degradation can be induced in PP by blending with PCG.

The tensile test results indicate that Young's modulus, tensile strength and percentage elongation generally decreased with increasing concentrations of PCG in the blended samples. An improvement in Young's modulus was observed at 90%PP/10%PCG. These results generally indicate very weak intermolecular bonding forces between PCG and polypropylene molecules. The low percentage elongation of the resulting polymer blends is attributed to the fact that PCG is highly glassy at ambient conditions in the absence of moisture compared to the pure polypropylene resin. The only exception was an improvement in Young's modulus at 90%PP/10%PCG. Thus the incorporation of PCG into PP at a concentration of 10% improves the modulus of the resulting blend.

There was an improvement in the hardness of PP with an increase in the concentration of PCG. The value increased to a maximum value of 61 HRF corresponding to the sample with concentration 60%PP/40%PCG, after which the value decreases with increase in PCG concentration. This general increase in hardness with increase in PCG concentration has been attributed to the good hardness properties of pure CG, although this occurs in the limit of appreciable compatibility between PP and PCG.

From impact test results, there was pronounced decrease in the impact strength of PP with the incorporation of PCG. This lowering effect has been linked to the phenomenon of plasticization

From this research work, PP has successfully been blended with PCG. The blended polymer samples were observed to undergo biodegradation in the presence of moisture more readily than the pure polymer samples. This is a possible means of controlling environmental pollution as the blended polymer samples easily degrade when discarded into the environment after use. This blending with PCG which is a non toxic substance implies the use of the blended samples in materials that have direct contact with food. It has also resulted in lowering the production cost of the polymer blends due to the abundant distribution of cashew in tropical and sub-tropical countries.

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Table 1. List of materials and their corresponding grades and source

Material	**Grade**	**Source**
Poly(vinylchloride), PVC (powder)	K Value: 65 Density: 1.37 g/cm^3	BDH
Polystyrene, PS (pellet)	*Mw*: 280 000 g/mol PDI: 2.2	BP Chemicals
Polypropylene, PP (pellet)	*Mw*: 360,000 g.mol^{-1} density: 0.90 g/cm^3 MFI: 16 g/10 minutes	TS 6100 (Quattor Petroquímica)
Anacardium occidentale gum	Natural exudates	Plantation garden in Ahmadu Bello University Zaria
Ethanol	Analytical	Aldrich
Benzene	Analytical	Aldrich
Chloroform	Analytical	Aldrich
Carbon Tetrachloride	Analytical	Aldrich
Cyclohexane	Analytical	Aldrich
Cyclohexanone	Analytical	Aldrich
Petroleum Ether	Analytical	Aldrich
Tetrahydrofuran	Analytical	Aldrich
Toluene	Analytical	Aldrich
1, 4-Dioxane	Analytical	Aldrich

Table 2. List of equipment used and their corresponding models.

Equipment	**Model**
General Laboratory Centrifuge	SORVIAL75066180
pH meter	Jenway 3505
Infrared spectrophotometer	Shimadzu FTIR-8400S
Two-roll mill	5183
Tensometer	Hounsfield
Carver Hand press	3851-0
Charpy Impact Tester	Cat. Nr.412
Indentec Universal Hardness Testing Machine	8187. 5L Kv model B

Table 3. PP/PCG blends composition.

Polymer : Gum (Weight % Ratio)	Polymer : Gum (Mass Ratio)
10 : 0	30.00 : 0.00
90 : 10	27.00 : 3.00
80 : 20	24.00 : 6.00
70 : 30	21.00 : 9.00
60 : 40	18.00 : 12.00
50 : 50	15.00 : 15.00
40 : 60	12.00 : 18.00
30 : 70	9.00 : 21.00
20 : 80	6.00 : 24.00
10 : 90	3.00 : 27.00

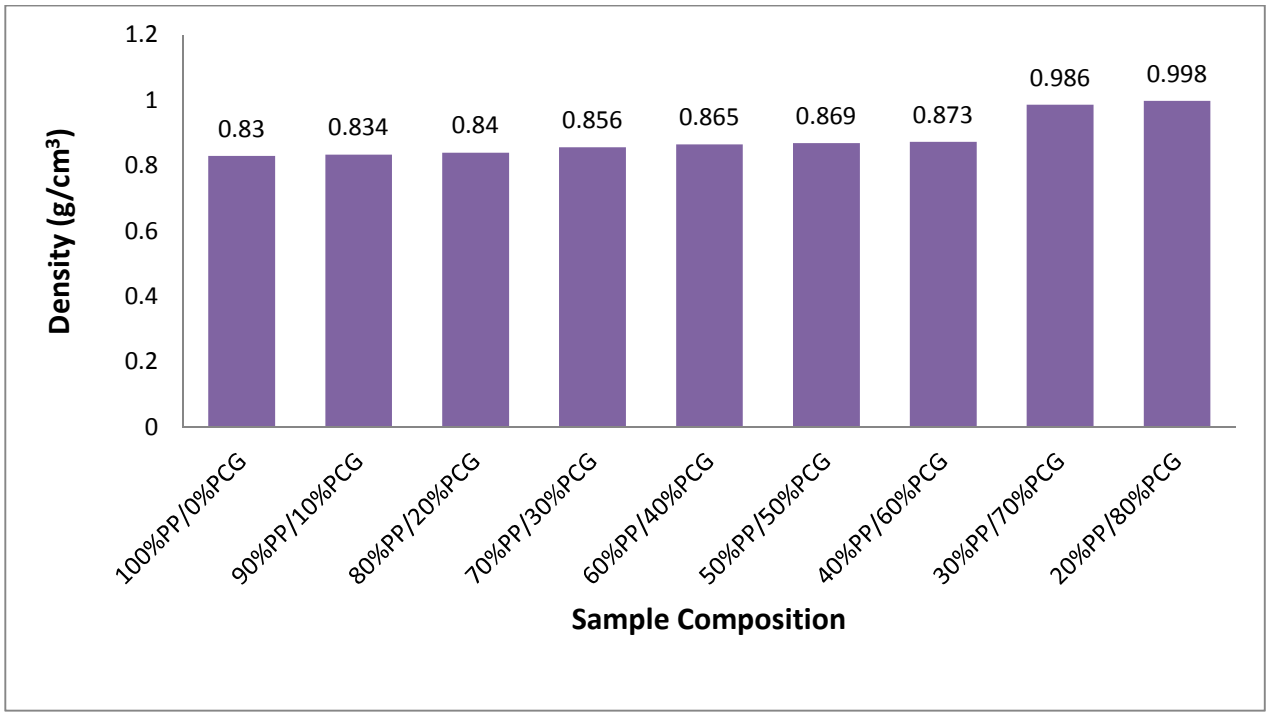

Fig. 1. Graphical representation of PP/PCG sample blend densities against their corresponding compositions.

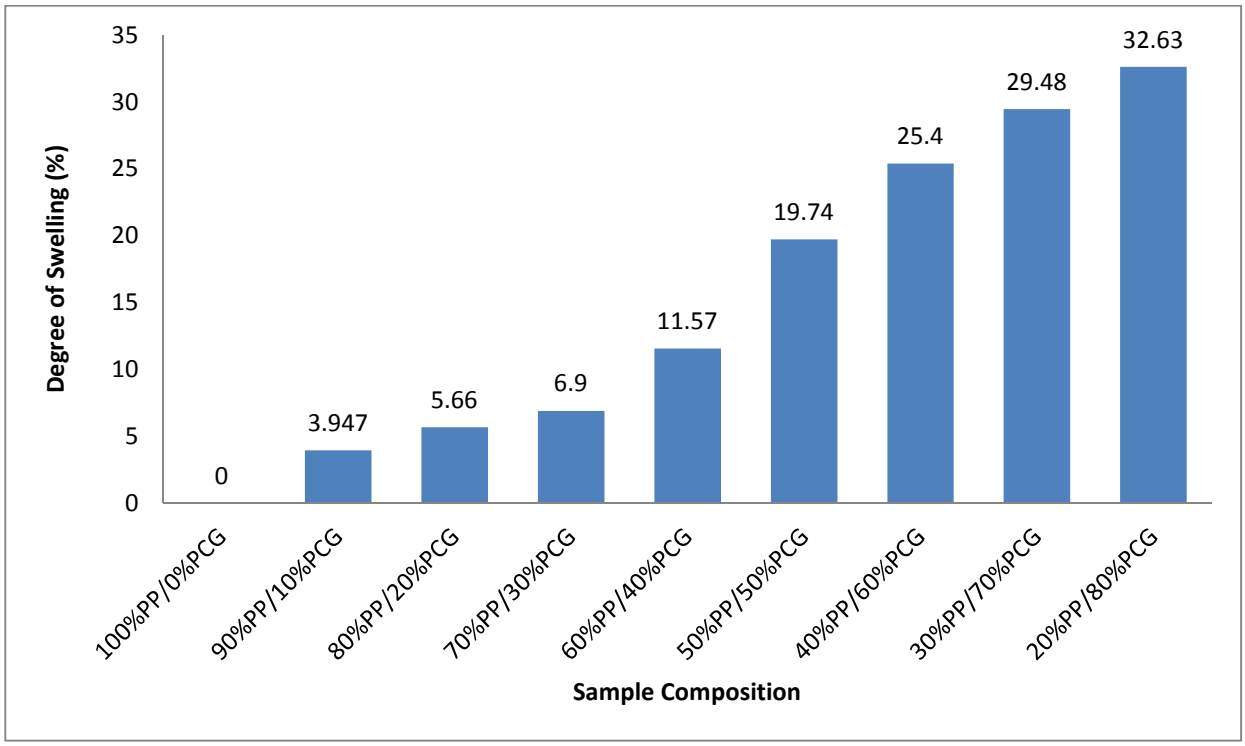

Fig. 2. DS values for various compositions of PP/PCG blends

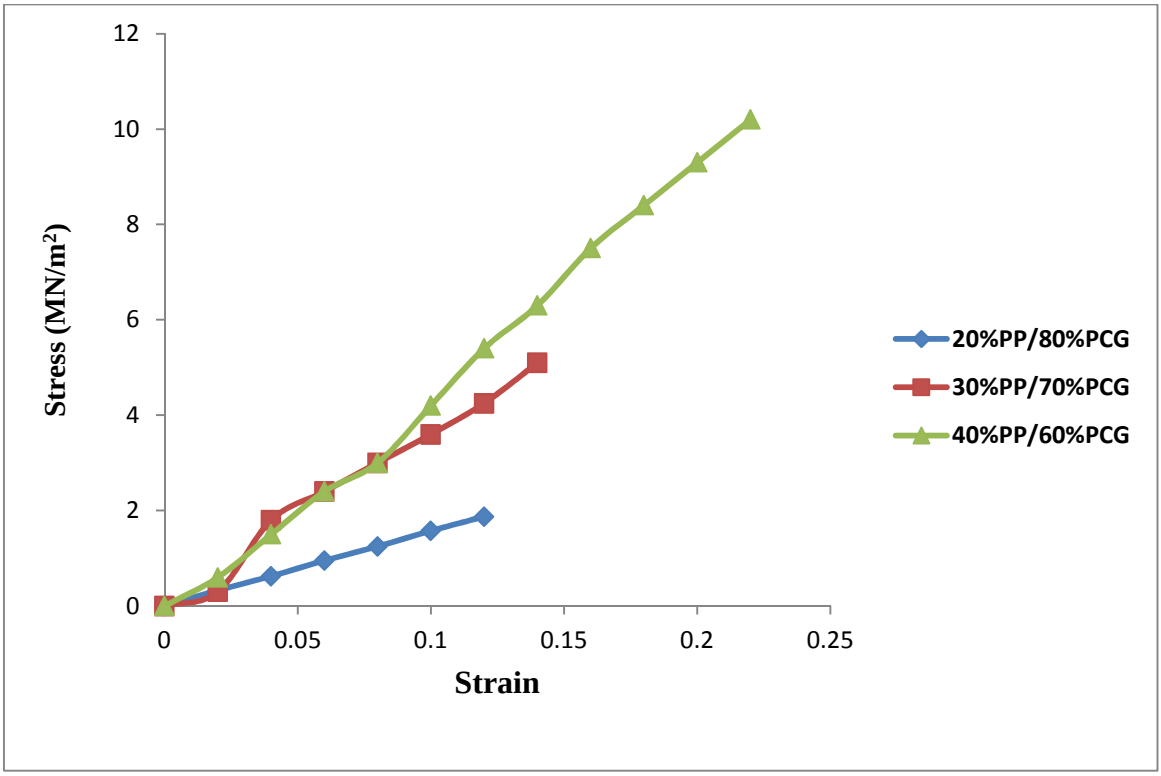

Fig. 3. Stress-strain curve of 20%PP/80%PCG, 30%PP/70%PCG and 40%PP/60%PCG.

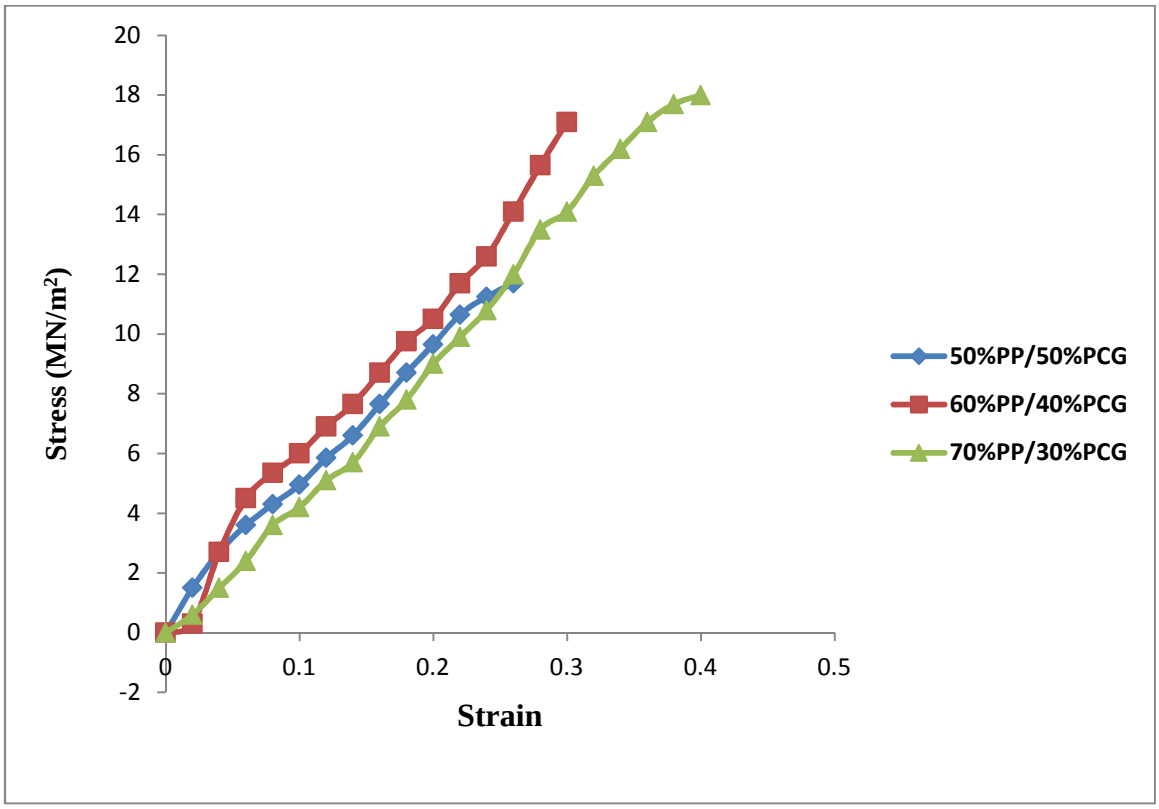

Fig. 4. Stress-strain curve of 50%PP/50%PCG, 60%PP/40%PCG and 70%PP/30%PCG.

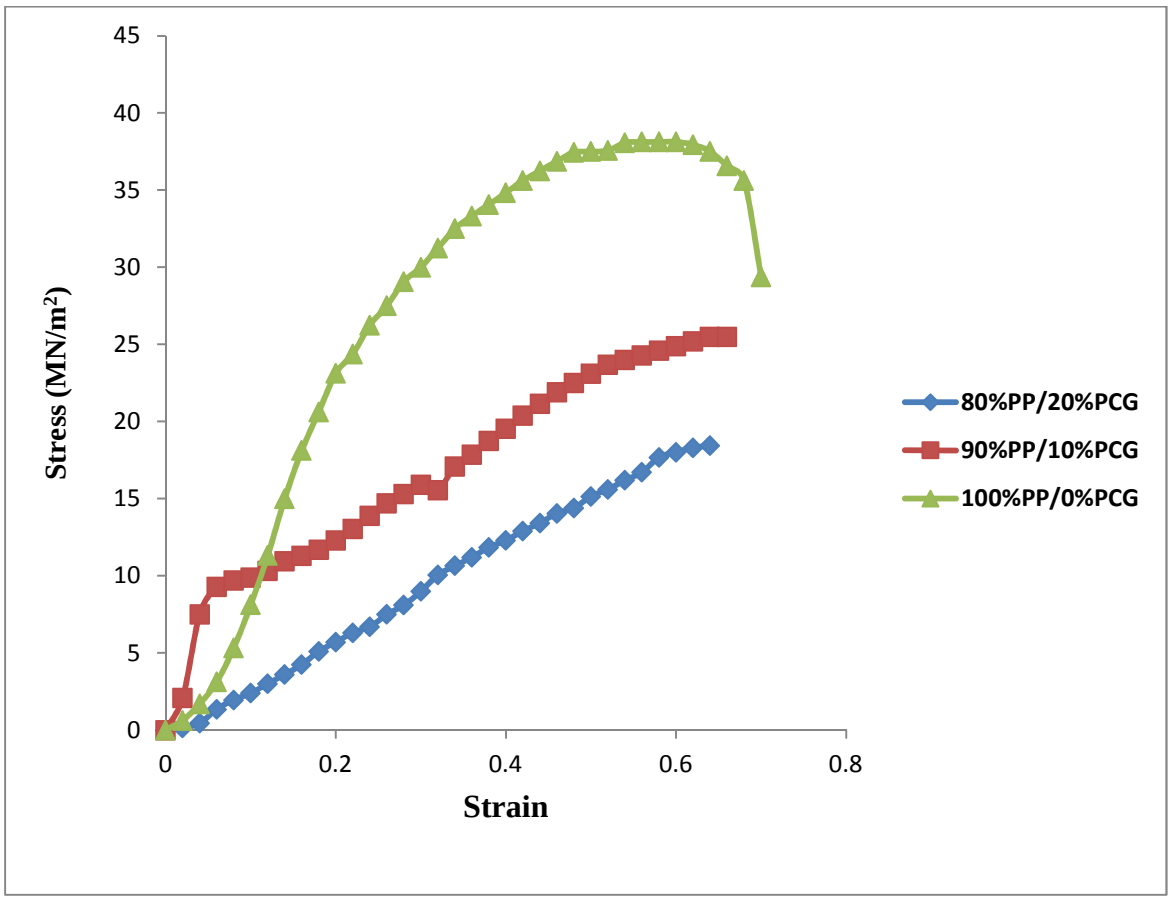

Fig. 5. Stress-strain curve of 80%PP/20%PCG, 90%PP/10%PCG and 1000%PP/0%PCG.

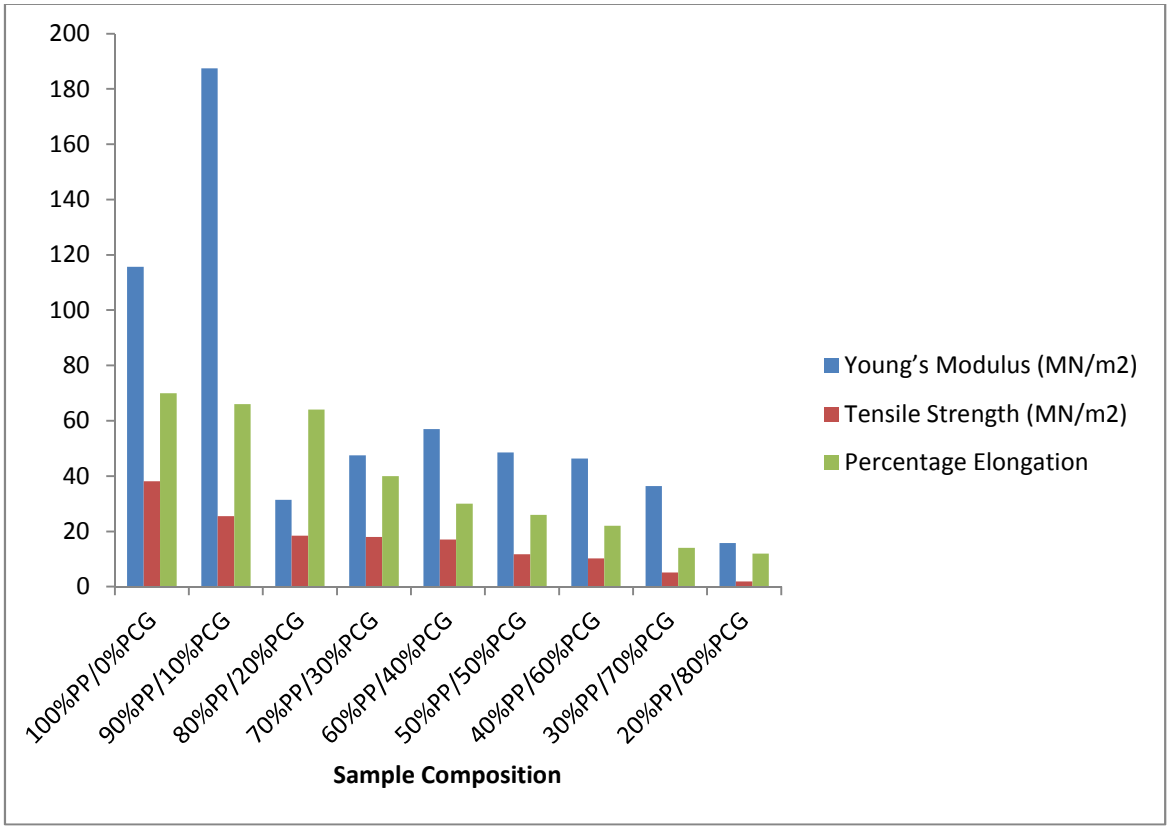

Fig. 6. Plot of Young's Modulus, Tensile Strength and Percentage Elongation of PP/PCG Blend Samples.

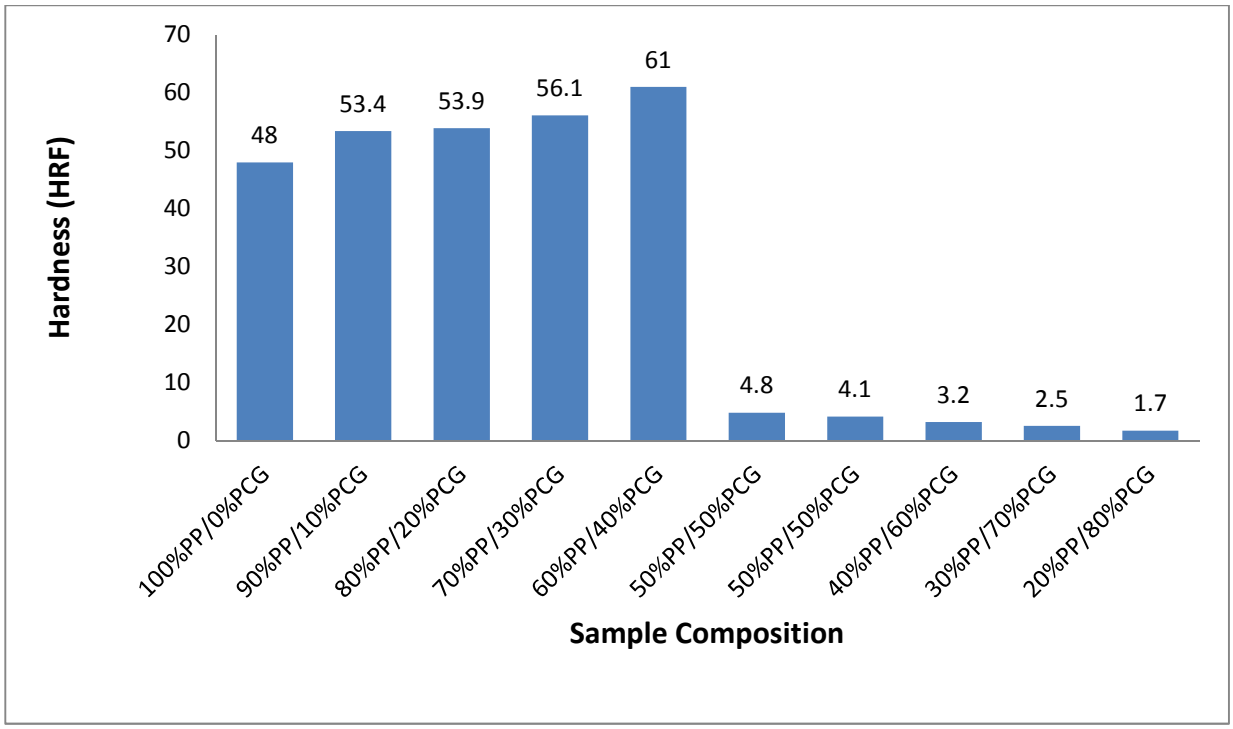

Fig. 7. Plot of hardness (HRF) against sample composition of PP/PCG blend samples

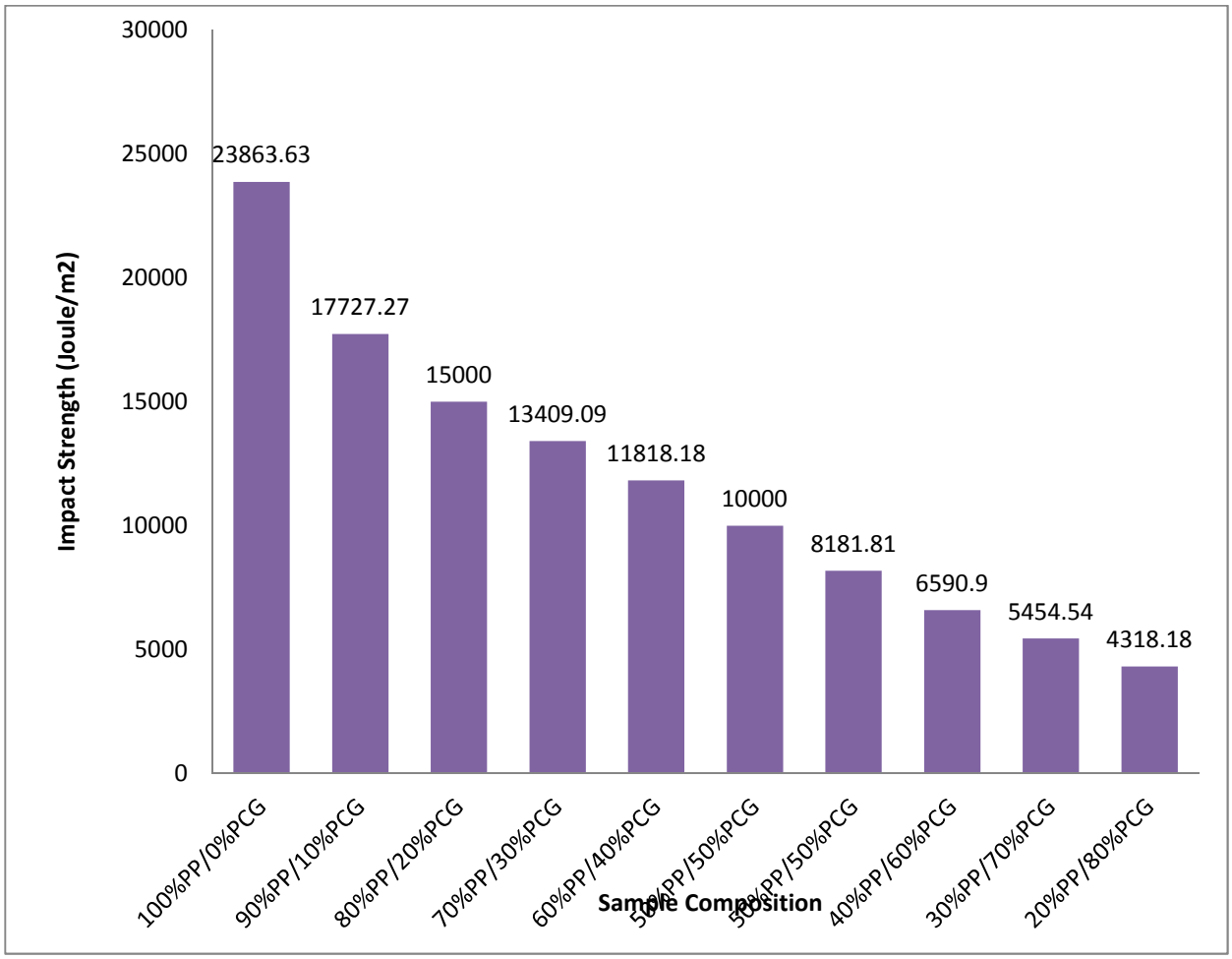

Fig. 8. Plot of impact strength against sample composition for PP/PCG sample blends.

APPENDIX

Appendix I: Density of Blended Samples

Table I.1: Density values of the various PP/PCG sample blends

Sample Code	Sample Composition	Density (g/cm^3)
310	100%PP/0%PCG	0.830
309	90%PP/10%PCG	0.834
308	80%PP/20%PCG	0.840
307	70%PP/30%PCG	0.856
306	60%PP/40%PCG	0.865
305	50%PP/50%PCG	0.869
304	40%PP/60%PCG	0.873
303	30%PP/70%PCG	0.986
302	20%PP/80%PCG	0.998

Appendix II: Water Sorption Analysis of Blended Samples

Tale II.1: Water sorption analysis result of PP/PCG blends

Sample Code	Sample Composition	DS or WL (%)
310	100%PP/0%PCG	0.00
309	90%PP/10%PCG	3.947
308	80%PP/20%PCG	5.66
307	70%PP/30%PCG	6.90
306	60%PP/40%PCG	11.57
305	50%PP/50%PCG	19.74
304	40%PP/60%PCG	25.40
303	30%PP/70%PCG	29.48
302	20%PP/80%PCG	32.63

Appendix III:

Stress Strain Relations of PP Blends

Table III.1: Tensile stress – strain relations of 20%PP/80%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.013	0.600	0.325	0.020
0.025	1.200	0.625	0.040
0.038	1.800	0.95	0.060
0.050	2.400	1.25	0.080
0.063	3.000	1.575	0.100
0.075	3.600	1.875	0.120

Table III.2: Tensile stress – strain relations of 30%PP/70%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.012	0.600	0.300	0.020
0.072	1.200	1.800	0.040
0.096	1.800	2.400	0.060
0.120	2.400	3.000	0.080
0.144	3.00	3.600	0.100
0.170	3.600	4.250	0.120
0.204	4.200	5.100	0.140

Table III.3: Tensile stress – strain relations of 40%PP/60%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.024	0.600	0.600	0.020
0.060	1.200	1.500	0.040
0.096	1.800	2.400	0.060
0.120	2.400	3.000	0.080
0.168	3.000	4.200	0.100
0.216	3.600	5.400	0.120
0.252	4.200	6.300	0.140
0.300	4.800	7.500	0.160
0.336	5.400	8.400	0.180
0.372	6.000	9.300	0.200
0.408	6.600	10.200	0.220

Table III.4: Tensile stress – strain relations of 50%PP/50%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.060	0.600		0.020
		1.500	
0.108	1.200		0.040
		2.700	
0.144	1.800		0.060
		3.600	
0.172	2.400	4.300	0.080
0.198	3.000		0.100
		4.950	
0.234	3.600		0.120
		5.850	
0.264	4.200		0.140
		6.600	
0.306	4.800		0.160
		7.650	
0.348	5.400		0.180
		8.700	
0.386	6.000		0.200
		9.650	
0.426	6.600		0.220
		10.650	
0.450	7.200		0.240
		11.250	
0.468	7.800	11.700	0.260

Table III.5: Tensile stress – strain relations of 60%PP/40%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.012	0.600		0.020
0.108	1.200	0.300	0.040
0.180	1.800	2.700	0.060
0.214	2.400	4.500	0.080
0.240	3.000	5.350	0.100
0.276	3.600	6.000	0.120
0.306	4.200	6.900	0.140
0.348	4.800	7.650	0.160
0.390	5.400	8.700	0.180
0.420	6.000	9.750	0.200
0.468	6.600	10.500	0.220
0.504	7.200	11.700	0.240
0.564	7.800	12.600	0.260
0.626	8.400	14.100	0.280
0.684	9.000	15.650 17.100	0.300

Table III.6: Tensile stress – strain relations of 70%PP/30%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.024	0.600	0.600	0.020
0.060	1.200	1.500	0.040
0.096	1.800	2.400	0.060
0.144	2.400	3.600	0.080
0.168	3.000	4.200	0.100
0.204	3.600	5.100	0.120
0.228	4.200	5.700	0.140
0.276	4.800	6.900	0.160
0.312	5.400	7.800	0.180
0.360	6.000	9.000	0.200
0.396	6.600	9.900	0.220
0.432	7.200	10.800	0.240
0.480	7.800	12.000	0.260
0.540	8.400	13.500	0.280
0.564	9.000	14.100	0.300
0.612	9.600	15.300	0.320
0.648	10.200	16.200	0.340
0.684	10.800	17.100	0.360
0.708	11.400	17.700	0.380
0.720	12.000	18.000	0.400

Table III.7: Tensile stress – strain relations of 80%PP/20%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.006	0.600	0.150	0.020
0.018	1.200	0.450	0.040
0.054	1.800	1.350	0.060
0.078	2.400	1.950	0.080
0.096	3.000	2.400	0.100
0.120	3.600	3.000	0.120
0.144	4.200	3.600	0.140
0.170	4.800	4.250	0.160
0.204	5.400	5.100	0.180
0.228	6.000	5.700	0.200
0.252	6.600	6.300	0.220
0.268	7.200	6.700	0.240
0.300	7.800	7.500	0.260
0.324	8.400	8.100	0.280
0.360	9.000	9.000	0.300
0.402	9.600	10.050	0.320
0.426	10.200	10.650	0.340
0.448	10.800	11.200	0.360
0.474	11.400	11.850	0.380
0.492	12.000	12.300	0.400
0.516	12.600	12.900	0.420
0.537	13.200	13.425	0.440
0.562	13.800	14.050	0.460
0.576	14.400	14.400	0.480
0.606	15.000	15.150	0.500
0.624	15.600	15.600	0.520
0.648	16.200	16.200	0.540
0.669	16.800	16.725	0.560
0.707	17.400	17.675	0.580
0.720	18.000	18.000	0.600
0.732	18.600	18.300	0.620
0.738	19.200	18.450	0.640

Table III.8: Tensile stress – strain relations of 90%PP/10%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.084	0.600	2.100	0.020
0.300	1.200	7.500	0.040
0.372	1.800	9.300	0.060
0.388	2.400	9.700	0.080
0.396	3.000	9.900	0.100
0.413	3.600	10.325	0.120
0.438	4.200	10.950	0.140
0.452	4.800	11.300	0.160
0.468	5.400	11.700	0.180
0.492	6.000	12.300	0.200
0.522	6.600	13.050	0.220
0.556	7.200	13.900	0.240
0.588	7.800	14.700	0.260
0.612	8.400	15.300	0.280
0.636	9.000	15.900	0.300
0.622	9.600	15.550	0.320
0.684	10.200	17.100	0.340
0.714	10.800	17.850	0.360
0.750	11.400	18.750	0.380
0.782	12.000	19.550	0.400
0.816	12.600	20.400	0.420
0.846	13.200	21.150	0.440
0.876	13.800	21.900	0.460
0.900	14.400	22.500	0.480
0.924	15.000	23.100	0.500
0.948	15.600	23.700	0.520
0.960	16.200	24.000	0.540
0.972	16.800	24.300	0.560
0.984	17.400	24.600	0.580
0.996	18.000	24.900	0.600
1.008	18.600	25.200	0.620
1.020	19.200	25.500	0.640
1.020	19.800	25.500	0.660

Table III.9: Tensile stress – strain relations of 100%PP/0%PCG

Load (KN)	Extension (mm)	Stress (MN/m^2)	Strain
0.000	0.000	0.000	0.000
0.025	0.600	0.625	0.020
0.068	1.200	1.700	0.040
0.125	1.800	3.125	0.060
0.213	2.400	5.325	0.080
0.325	3.000	8.125	0.100
0.453	3.600	11.325	0.120
0.600	4.200	15.000	0.140
0.725	4.800	18.125	0.160
0.825	5.400	20.625	0.180
0.925	6.000	23.125	0.200
0.975	6.600	24.375	0.220
1.050	7.200	26.250	0.240
1.100	7.800	27.500	0.260
1.163	8.400	29.075	0.280
1.200	9.000	30.000	0.300
1.250	9.600	31.250	0.320
1.300	10.200	32.500	0.340
1.333	10.800	33.325	0.360
1.363	11.400	34.075	0.380
1.393	12.000	34.825	0.400
1.425	12.600	35.625	0.420
1.450	13.200	36.250	0.440
1.475	13.800	36.875	0.460
1.498	14.400		0.480
		37.450	
1.500	15.000		0.500
		37.500	
1.503	15.600		0.520
		37.575	
1.523	16.200	38.075	0.540
1.525	16.800	38.125	0.560
1.525	17.400	38.125	0.580
1.525	18.000	38.125	0.600
1.518	18.600	37.950	0.620
1.500	19.200	37.500	0.640
1.463	19.800	36.575	0.660
1.425	20.400	35.625	0.680
1.175	21.000	29.375	0.700

Appendix IV: Summary of Tensile Test Analyses

Table IV.1: Summary of tensile test analyses of PP/PCG Blend Samples

Sample Code	Sample Composition	Young's Modulus (MN/m^2)	Tensile Strength (MN/m^2)	Percentage Elongation
310	100%PP/0%PCG	115.625	38.125	70.000
309	90%PP/10%PCG	187.500	25.500	66.000
308	80%PP/20%PCG	31.406	18.450	64.000
307	70%PP/30%PCG	47.500	18.000	40.000
306	60%PP/40%PCG	57.000	17.100	30.000
305	50%PP/50%PCG	48.490	11.700	26.000
304	40%PP/60%PCG	46.360	10.200	22.000
303	30%PP/70%PCG	36.420	5.100	14.000
302	20%PP/80%PCG	15.750	1.875	12.000

Appendix V: Hardness Test Results

Table V.1: Hardness (HRF) Values for PP/PCG blended samples

Sample Code	Sample Composition	HRF Value
310	100%PP/0%PCG	48.00
309	90%PP/10%PCG	53.40
308	80%PP/20%PCG	53.90
307	70%PP/30%PCG	56.10
306	60%PP/40%PCG	61.00
305	50%PP/50%PCG	4.800
305B	50%PP/50%PCG	4.10
304	40%PP/60%PCG	3.20
303	30%PP/70%PCG	2.50
302	20%PP/80%PCG	1.70

Appendix VI: Impact Test Results

Table VI.1: Charpy impact test values for PP/PCG blended samples

Sample Code	Sample Composition	Fracture Area (m^2)	Impact Energy (Joule's)	Impact Strength (Joule/m^2)
310	100%PP/0%PCG	4.400×10^{-5}	1.05	23863.63
309	90%PP/10%PCG	4.400×10^{-5}	0.78	17727.27
308	80%PP/20%PCG	4.400×10^{-5}	0.66	15000.00
307	70%PP/30%PCG	4.400×10^{-5}	0.59	13409.09
306	60%PP/40%PCG	4.400×10^{-5}	0.52	11818.18
305	50%PP/50%PCG	4.400×10^{-5}	0.44	10000.00
305B	50%PP/50%PCG	4.400×10^{-5}	0.36	8181.81
304	40%PP/60%PCG	4.400×10^{-5}	0.29	6590.90
303	30%PP/70%PCG	4.400×10^{-5}	0.24	5454.54
302	20%PP/80%PCG	4.400×10^{-5}	0.19	4318.18