Morphology and Physical/End-Use Properties of Recycled Polypropylene-Corn Cob Powder Composites

Chukwudike Onuoha¹,a*, Okechukwu Onyemaobi²,b, Charles Anyakwo³,c and Genevieve Onuegbu⁴,d

¹-³Department of Materials and Metallurgical Engineering, Federal University of Technology, Owerri, Nigeria
⁴Department of Polymer and Textile Engineering, Federal University of Technology, Owerri, Nigeria

a*chukwudikeonuoha@gmail.com, bonyemaob@yahoo.com, ccharlesanyakwo@yahoo.com, dgc.onuegbu@yahoo.com

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Abstract. This study investigates the morphological and physical/end-use properties of corn cob powder-filled recycled polypropylene composites. The composites were prepared by incorporating corn cob powder of particle sizes 150 µm, 300 µm and 425 µm respectively at filler loadings of 5 to 25 wt%. The properties were determined according to standard test procedures. Results showed that the incorporation of corn cob powder as filler resulted to enhancement of water absorption and solvent sorption, which were found to increase with both increase in filler loading and increase in filler particle size, probably due to the hydrophilic nature of corn cob powder. It was also discovered that solvent sorption was most pronounced with benzene, followed by toluene and lastly xylene, in accordance with the relative proximity of their solubility parameters to that of polypropylene. Flame propagation rate was also found to improve by the incorporation of corn cob powder due to its high content of cellulose, a combustible organic matter. However, specific gravities of the composites were found to be lower than for the unfilled polypropylene, an implication that the composites produced are lighter in weight than the unfilled. Specific gravity increased with increase in filler loading but decreased with increase in particle size. The Morphological studies showed increase in the number of spherulites with increase in filler loading and increase in the size of the spherulites with increase in particle size. Further observation showed that the particle sizes and pores sizes detected increased with increase in filler particle size probably due to poor interaction and distribution of coarse particles. It is hoped that this present study will help place the usefulness of corn cob as filler in the development of thermoplastic composites in future and develop its niche in the scientific record.

Introduction

There is a growing interest in the use of natural/bio-fibers/fillers as reinforcements for biodegradable polymers because natural/bio-fibers/fillers have the functional capability to substitute for glass fibers. Furthermore, rising oil prices and increased activity in regards to environmental pollution prevention have also pushed recent research and development of biodegradable polymers. In light of petroleum shortages and pressures for decreasing the dependence on petroleum products, there is an increasing interest in maximizing the use of renewable materials. The use of agricultural resources as source of raw materials to the industry not only provides a renewable source, but could also generate a non-food source of economic development for farming and rural areas. Appropriate research and development in the area of agricultural based fillers/fibers filled plastics could lead to new value-added, non-food uses of agricultural materials. The cost of natural fibers are in general less than the plastic, and thus high fiber loading can result in significant material cost savings. The cost of compounding is unlikely to be much more than for conventional mineral/inorganic based presently used by plastics industry. Significant environmental advantages include: preservation of...
fossil-based raw materials; complete biological degradability; reduction in the volume of refuse; reduction of carbon dioxide released to the atmosphere; as well as increased utilization of agricultural resources. The most important advantages of using polymers are, ease of processing, high productivity and low cost, in combination with their versatility [1].

However, there are some drawbacks too, such as low microbial resistance, high moisture absorption of natural fibers that can result in swelling of the fibres which arouse concern about the dimensional stability of the agro or natural fibre composites. Other than that, the main drawback of the use of natural fibre as fillers is the low processing temperature permissible due to the possibility of fibre degradation and/or the possibility of volatile emissions that could affect the composite properties. Agro-residue or field crop such as cereal straw, flax straw, rice husk, bagasse, cornstalk, wheat straw and corncob which categorized as natural fibres are recently being considered as an alternative for the wood-plastic composites which are at present dominating the natural fibre-composite market [2,3].

The addition of fillers to polypropylene would generally have some positive effect on its mechanical properties but even such, some drawbacks are also bound to be as most fillers and reinforcements are polar and polypropylene being a non-polar, it will result to poor adhesion between the filler and the polymer. This incompatibility will lead to poor dispersion and insufficient reinforcement with accompanying poor mechanical properties. Thus, solution to solve this problem would be incorporating a compatibilizer [2,4].

Plastic waste is a major component of global municipal solid waste and presents a promising raw material source for composite production. Hence, the development of new value-added products, with the aim of utilizing agro wastes and low cost recycled thermoplastics (which would otherwise be added to landfills) is assuming greater importance [5].

Plastic industry uses inorganic fillers such as talc, calcium carbonate, mica and glass or carbon fibres to modify the performance of thermoplastics. Inorganic fillers provide rigidity and temperature resistance; however, these fillers are costly and abrasive to the processing equipment [6].

Recently, organic fillers produced from agricultural wastes have gained tremendous attention from plastic industry. The primary advantages of using organic fillers in thermoplastics can be listed as low densities, low cost, non-abrasiveness, high filling levels, low energy consumption, biodegradability, availability of a wide variety of fibres throughout the world and generation of a rural/agricultural-based economy [7].

Corn cob (CC), also spelled corn cob, is the central core of an ear of maize (Zea mays sp.). It is the part of the ear on which the kernels grow. The ear is also considered a "cob" or "pole" but it is not fully a "pole" until the ear is shucked, or removed from the plant material around the ear [8]. The innermost part of the cob is white and has a consistency similar to foam plastic.

Corn cob is a lignocellulosic material composed of cellulose (38.8% + 2.5%), hemicellulose (44.4% + 5.2%) and lignin (11.9% + 2.3%). These polymeric fibres consist of monomeric molecules. Cellulose is built of C₆ sugars; hemicellulose mainly of the C₅; sugars xylose and arabinose and lignin consists of phenolic macromolecules [9].

Corncobs find use as industrial source of the chemical furfural, fibre in fodder for ruminant livestock (despite low nutritional value), thickeners that can be added to soup stock or made into traditional sweetened corn cob jelly, bedding for animals as cobs absorb moisture and provide a compliant surface, a mild abrasive for cleaning building surfaces, when coarsely ground, biofuel and charcoal production [10,8].

Much research efforts are geared towards possible ways of recycling wastes for reuse to keep environment clean and safe. Corn cobs are available in abundance, nontoxic, biodegradable and cheap. Hence, the use of corn cob in producing recycled polypropylene composites is therefore hoped to convert wastes to wealth, tackle the problem of environmental pollution, reduce the material cost and produce biodegradable composites.
Materials and Methods

Polypropylene (PP) used in this research was a product of SK Global Chemicals Limited, Korea obtained from CeePlast Limited Aba, Abia State. It has a melt flow index of 0.4g/10 min at 230 °C and density of 0.922g/cm³.

Recycled polypropylene was sourced from Ihiagwa village, Owerri West L.G.A., Imo State and was thoroughly washed, dried and sliced to tiny pieces.

The compatibilizer; maleic anhydride-grafted-polyethylene (MAPE) used was bought from CEEPlast Industry, Aba, a product of Sigma Aldarich Company, U.S.A. It has the following properties: maleic anhydride = 0.5 wt%, viscosity = 500 cP (140 °C) and saponification value = 60 KOH/g.

Corn cobs were sourced locally from Iyalu Ibere, Ikwuano Local Government Area of Abia State, Nigeria. The cobs were properly cleaned, dried, ground and sieved to three sieve sizes namely 150, 300 and 425 μm.

Preparation of Polypropylene Composites

The polypropylene composites of corn cob powder were prepared by thoroughly mixing 100g of virgin polypropylene and 100g of recycled polypropylene with appropriate filler contents (5, 10, 15, 20 and 25 wt%). Two control samples were prepared; (1) by using 200 g of virgin PP only and (2) by mixing 100 g of virgin PP and 100 g of recycled PP without the addition of any filler as shown in Table 1.

<table>
<thead>
<tr>
<th>Code</th>
<th>Virgin PP (g)</th>
<th>Recycled PP (g)</th>
<th>CC (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V (Control 1)</td>
<td>200</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>VR (Control 2)</td>
<td>100</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>C1</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>C2</td>
<td>100</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>C3</td>
<td>100</td>
<td>100</td>
<td>15</td>
</tr>
<tr>
<td>C4</td>
<td>100</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>C5</td>
<td>100</td>
<td>100</td>
<td>25</td>
</tr>
</tbody>
</table>

Each mixture was melted and homogenized with the filler in an injection moulding machine. The operation was carried out at an injection pressure of 100 kgf/cm² (9.81 MPa) and temperature of 200 °C. The mixture was then extruded as sheets with dimensions of 150 x 150 x 4mm. Test samples were prepared from the sheets for the physical properties testing. This was done for the three particle sizes studied.

Determination of Specific Gravity (Relative Density) Test

The hydrostatic weighing method was used in this test. Since the samples float and do not sink in water unaided, a less dense liquid such as gasoline was used for this test instead of water. A massless thread was used in suspending the specimens in air and gasoline during measurement by means of a sensitive spring balance. The test specimen was first weighed in air to obtain the weight in air (\(W_{s,\text{air}}\)) and later immersed in gasoline to obtain the weight in gasoline (\(W_{s,\text{gas.}}\)). The specific gravity of the specimen with respect to gasoline was calculated as follows:

\[
\text{Specific gravity wrt gasoline, } SG_{\text{wrtgas.}} = \frac{W_{s,\text{air}}}{W_{s,\text{air}} - W_{s,\text{gas.}}} \tag{1}
\]
The actual specific gravity of the sample (i.e. relative to water) was calculated by multiplying equation (1) with the specific gravity of gasoline

\[
Specific \ gravity \ of \ sample, \ SG = \left( \frac{W_{s,\text{air}}}{W_{s,\text{air}} - W_{s,\text{gas}}} \right) \times 0.74
\]  
(2)

where the specific gravity of gasoline = 0.74.

Determination of Water Absorption

This was determined according to ASTM procedure (ASTM D96-06). Rectangular specimens were cut from each sample and weighed to the nearest 0.001g. The samples were immersed in water for 24 hours at room temperature. Excess water on sample surface was removed before reweighing. The percentage increase in mass during immersion was calculated to the nearest 0.01% using the following equation:

\[
A_W (\%) = \frac{\text{Weight after 24 hrs} - \text{initial weight}}{\text{initial weight}} \times 100
\]  
(3)

Determination of Flame Retardant Property

This was determined using a modification of ASTM D 4804. A 10 mm mark was measured and marked out on each of the cut samples. The specimen was then clamped horizontally on a retort stand with the marked 10 mm distance protruding out of the clamp. The free end of each sample was ignited and the time taken for the sample to ignite recorded as the ignition time (I). The sample was allowed to burn to the 10 mm mark (D) and the propagation time (P) was recorded. The rate of burning was calculated using the equation:

\[
\text{Rate of burning (mm/s)} = \frac{D}{P - I}
\]  
(4)

where \(D\) = Propagation distance (mm), \(P\) = Flame propagation time (s), \(I\) = Ignition time (s).

Determination of Solvent Sorption (Swelling Behaviour)

Samples were cut from the composites, weighed, labeled and put into 3 sample bottles labeled B, T and X. Thirty millilitres of benzene, toluene and xylene were respectively poured into the sample bottles. The set-up was left at room temperature for 24 hours. At expiration, each sample was removed from the bottle. The solvents adhering to the surface of the samples were carefully wiped out using filter papers. The net sample was weighed and recorded as follows:

\[M_1 = \text{Mass of dry sample (g)}\]
\[M_2 = \text{Mass of wet sample (g)}\]
\[\Delta M = \text{Change in mass (M}_2 - M_1) \text{ (g)}\]

The molar percentage uptake of each solvent per gram of the composite (Q_s) was calculated using the formula:

\[Q_s = \left( \frac{\text{Mass of solvent}}{\text{Molar mass of solvent}} \right) \times \frac{\text{Initial Mass of solute}}{M_1} \times 100\%\]

i.e.

\[Q_s = \left( \frac{\Delta M}{\text{Molar mass of solvent}} \right) \times \frac{\text{Initial Mass of solute}}{M_1} \times 100\%\]  
(5)

Morphological analysis was also carried out using Scanning Electron Microscope (Phenom: product of Phenom World, Eindhoven, Netherlands; Model: ProX). The specimen was made conductive by introducing a minimum of a 5nm gold onto it and then cut into 2 x 2 mm using a sputter cutting machine. The sample was then placed on the column of the Scanning Electron Microscope (SEM) where the image was focused on navigation camera and then transferred to
electron mode in accordance to the desired magnification e.g. 50, 80, 100 or 200µm. The samples were thus analyzed to determine the microstructure of the composites, from which the distribution, orientation and interaction of the fillers in the composite and the interfacial adhesion of the filler and polymer matrix were examined.

Results and Discussion

Results of Physical and End-Use Properties: Specific Gravity, Water Absorption, Flame Propagation and Solvent Sorption (Swelling Behaviour) as influenced by filler loading and filler particle size are presented in Tables 2. The physical and end-use properties of the two controls are also included in Tables 2, to serve as references for comparing the effect of filler loading and filler particle size. It can be generally observed that all the physical and end-use properties investigated increased with increase in filler loading, except flame propagation rate which decreased with increase in filler loading. Furthermore, the general trend observed is that all the end-use properties of the filled polypropylene composites (except specific gravity) are higher than those of the unfilled polypropylene.

Table 2. Result of Physical and End-use properties of PP-CC Composites.

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Filler Loading (Wt %)</th>
<th>PHYSICAL AND END-USE PROPERTIES*&lt;br&gt;S.G</th>
<th>W.A (%)</th>
<th>F.P (mm/s)</th>
<th>S.S (Mole %)/g&lt;br&gt;Benzene</th>
<th>Toluene</th>
<th>Xylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 µm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>0</td>
<td>0.92</td>
<td>0.27</td>
<td>0.29</td>
<td>0.0546</td>
<td>0.0418</td>
<td>0.0372</td>
</tr>
<tr>
<td>VR</td>
<td>0</td>
<td>0.91</td>
<td>0.29</td>
<td>0.33</td>
<td>0.0546</td>
<td>0.0442</td>
<td>0.0381</td>
</tr>
<tr>
<td>C_1</td>
<td>5</td>
<td>0.86</td>
<td>0.83</td>
<td>0.38</td>
<td>0.0546</td>
<td>0.0598</td>
<td>0.0433</td>
</tr>
<tr>
<td>C_2</td>
<td>10</td>
<td>0.87</td>
<td>1.06</td>
<td>0.36</td>
<td>0.0781</td>
<td>0.0650</td>
<td>0.0457</td>
</tr>
<tr>
<td>C_3</td>
<td>15</td>
<td>0.89</td>
<td>1.24</td>
<td>0.35</td>
<td>0.0837</td>
<td>0.0653</td>
<td>0.0517</td>
</tr>
<tr>
<td>C_4</td>
<td>20</td>
<td>0.89</td>
<td>1.49</td>
<td>0.34</td>
<td>0.0839</td>
<td>0.0672</td>
<td>0.0574</td>
</tr>
<tr>
<td>C_5</td>
<td>25</td>
<td>0.90</td>
<td>2.29</td>
<td>0.31</td>
<td>0.0915</td>
<td>0.0851</td>
<td>0.0631</td>
</tr>
<tr>
<td>300 µm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_6</td>
<td>5</td>
<td>0.84</td>
<td>1.19</td>
<td>0.36</td>
<td>0.0659</td>
<td>0.0690</td>
<td>0.0420</td>
</tr>
<tr>
<td>C_7</td>
<td>10</td>
<td>0.85</td>
<td>1.58</td>
<td>0.35</td>
<td>0.0783</td>
<td>0.0634</td>
<td>0.0437</td>
</tr>
<tr>
<td>C_8</td>
<td>15</td>
<td>0.86</td>
<td>2.17</td>
<td>0.33</td>
<td>0.0834</td>
<td>0.0691</td>
<td>0.0446</td>
</tr>
<tr>
<td>C_9</td>
<td>20</td>
<td>0.88</td>
<td>2.26</td>
<td>0.29</td>
<td>0.0858</td>
<td>0.0736</td>
<td>0.0495</td>
</tr>
<tr>
<td>C_10</td>
<td>25</td>
<td>0.89</td>
<td>2.70</td>
<td>0.26</td>
<td>0.0925</td>
<td>0.0903</td>
<td>0.0500</td>
</tr>
<tr>
<td>425 µm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_11</td>
<td>5</td>
<td>0.83</td>
<td>2.14</td>
<td>0.38</td>
<td>0.0729</td>
<td>0.0802</td>
<td>0.0450</td>
</tr>
<tr>
<td>C_12</td>
<td>10</td>
<td>0.84</td>
<td>2.42</td>
<td>0.37</td>
<td>0.0858</td>
<td>0.0840</td>
<td>0.0592</td>
</tr>
<tr>
<td>C_13</td>
<td>15</td>
<td>0.85</td>
<td>2.76</td>
<td>0.36</td>
<td>0.0914</td>
<td>0.0867</td>
<td>0.0650</td>
</tr>
<tr>
<td>C_14</td>
<td>20</td>
<td>0.85</td>
<td>2.84</td>
<td>0.33</td>
<td>0.0946</td>
<td>0.0900</td>
<td>0.0677</td>
</tr>
<tr>
<td>C_15</td>
<td>25</td>
<td>0.87</td>
<td>2.88</td>
<td>0.29</td>
<td>0.0962</td>
<td>0.0944</td>
<td>0.0704</td>
</tr>
</tbody>
</table>


It can be seen from Table 2 that the initial increase or decrease in the physical and end-use properties was as a result of the incorporation of the recycled PP into the virgin PP. This change in behaviour (compare data for sample V and sample VR) is probably due to the fact that recycled PP is less plastic and hence harder than virgin PP. Therefore, it can be said that the recycled PP acted as filler. However, sample V was chosen here as the control since the effect of recycled PP is the same on all the composites because they all contained the same amount of recycled PP.
The result of specific gravity is shown in Fig. 1. From the result, it can be seen that the specific gravities of the filled samples are lower than the control at all the filler loadings and filler particle size studied. This can be attributed to the fact that Corn cob is lighter in weight and occupies a substantial amount of space, resulting to lighter composites.

The increase in specific gravity with increase in filler loading is probably due to the better distribution of the filler in the polymer matrix. The decrease in the specific gravity or relative density with increase in the filler particle size is attributable to the greater uniform distribution of the smaller sized fillers in the polymer matrix and the better packing efficiency of small particles within the matrix. That is, more stuff was packed in the same volume compared to when large filler particles were used. Large sized filler particles packed less efficiently and contributed less to the density of the PP. This means that coarse filler particles led to poor dispersion of filler resulting in agglomeration and consequent reduction in specific gravity, evident in the decrease of specific gravity at larger particle sizes. This result is in agreement with earlier works carried out for bean pod particulate. This work is in agreement with earlier works carried out by [11 and 12].

![Specific Gravity vs Filler Loading](image)

**Figure 1.** Variation of Specific Gravity with Filler Loading.

Result of water sorption is shown graphically in Fig. 2. It can be observed that water sorption increased with increase in both filler loading and particle size, with the least values obtained at 5wt% loading and 150 μm particle size. The observed increase in water sorption with increase in filler loading is attributable to the enhanced surface area to volume ratio, provided by enhanced incorporation of the filler. Water sorption can be by adsorption and absorption which are surface dependent phenomena. High filler loading implies incorporating more particles in the PP and increasing the total surface area for water sorption. In addition to large surface area, corn cob is hydrophilic in nature and its incorporation into the polymer matrix enhanced the water sorption capacity of the composites. Hence, increasing the content of the hydrophilic filler led to increase in water sorption of the composites.

Also, with larger particle sizes, there is the difficulty of achieving a homogeneous dispersion of fillers resulting in agglomeration of filler with consequent creation of voids (increased porosity) in the system. As a result, water molecules could more easily penetrate the interior of the polymer composite, leading to higher water sorption. Similar behaviour was reported by [12,11,7]
Result of flame retardant property is shown in Fig. 3. It can be observed from the result that, values obtained for the filled samples are higher than for the unfilled sample except at 25wt% filler content for 300 and 425 µm particle sizes. It was also found that flame propagation rate decreased with increase in filler loading. 425 µm particle size had the highest flame propagation rate between 5 and 15 wt% filler loading, followed by 150 µm and lastly 300 µm. Above 15 wt%, 150 µm particle size had the highest value, followed by 425 µm. It is evident that the incorporation of corn cob powder into polypropylene generally did not enhance its flame retardant property, an indication that corn cob enhanced the combustibility of PP probably due to its high content of cellulose, a combustible organic matter. This is similar to the findings of [7].

Results of solvent sorption (expressed in mole % of solvent per gram of polymer) of the composites in benzene, toluene and xylene are presented graphically in Figs. 4, 5 and 6 for 150, 300 and 425 µm particle sizes respectively. Solvent sorption values of the filled samples were found to be higher than the unfilled in all particle sizes studied.

It can be observed that solvent sorption increased with increase in filler loading at all particle sizes studied. This trend in behaviour is probably due to the high surface area to volume ratio of the particles with increased filler content. Hence, at higher filler loading, more filler particles were present which resulted in increased molar solvent sorption.

Solvent sorption also increased with increase in particle size at any chosen filler loading. This increase of solvent sorption with increase in particle size can be attributed to the fact that larger particles create more voids in the system as a result of poor dispersion in the matrix. The voids created provide better absorption sites in the system leading to more solvent sorption.
It is also observed that highest solvent sorption occurred in benzene, followed by toluene and lastly xylene. The reason for this trend could be due to the relative proximity of the solubility parameters of the solvents to that of polypropylene. Another possible factor could be the molar masses of the solvents.

Solubility or swelling behaviour is favoured if solubility parameters of the polymer and the solvent are close, but is not favoured if the parameters are much wider. Polypropylene has a solubility parameter of 9.4 (cal/cm$^3$)$^{1/2}$ [13], benzene 9.2 (cal/cm$^3$)$^{1/2}$, toluene 8.82 (cal/cm$^3$)$^{1/2}$ and xylene 8.64 (cal/cm$^3$)$^{1/2}$ [14]. It can be observed that the solvent whose solubility parameter is closest to that of polypropylene (9.3) is benzene (9.1), followed by toluene (8.9) and finally xylene (8.8). Based on the theory of polymer solutions and solubility, it is expected that benzene should be absorbed the most by polypropylene. This swelling behaviour should decrease progressively in the presence of toluene and xylene.

As for the effect of molar mass of solvent, it was observed that molar solvent sorption increased as the molar mass of solvent decreased. Thus, benzene with a molar mass of 78.11 g/mole, had the highest molar solvent sorption by polypropylene, followed by toluene (92.14 g/mole) and xylene (106.16 g/mole) in that order. A possible explanation for this could be that the polymer (polypropylene) found it easier to absorb low molecular mass solvents compared to those of high molecular mass.

![Figure 4](image1.png)

**Figure 4.** Variation of Solvent Sorption with Filler Loading at 150 µm Particle Size.

![Figure 5](image2.png)

**Figure 5.** Variation of Solvent Sorption with Filler Loading at 300 µm Particle Size.
The morphological analysis of the some selected composites was done using Scanning Electron Microscope and the micrographs are showed in Figs. 7 to 10. It can be seen that the incorporation of filler into the polypropylene matrix resulted to increase in the number of spherulites in the structure as a result of increase in nucleation sites. More spherulites can be observed in the filled samples than in the control. Also, increase in filler particle size resulted in increase in the size of the spherulites.

Spherulites are spherical semicrystalline regions inside non-branched linear polymers. Their formation is associated with crystallization of polymers from the melt and is controlled by several parameters such as the number of nucleation sites (induced by impurities, plasticizers, fillers, dyes and other substances added to improve other properties of the polymer), structure of the polymer molecules, cooling rate, etc. Formation of spherulites affects many properties of the polymer material; in particular, crystallinity, density, tensile strength and Young's modulus of polymers increase during spherulization.

The micrographs of the filled samples when compared to the control revealed that there is enhanced spherulization owing to presence of nucleation sites provided by the incorporation of fillers. However, at larger filler particles sizes for a chosen filler loading, there is poor dispersion of the fillers leading to cluster of the spherulites and subsequent increase in the size of the spherulites. This is because the larger filler particles have the tendency to grow larger than the tiny particles leading to cluster of the spherulites due to their interaction with each other, observable in Figs. 10.

Additionally, the analysis of the distribution of filler particles and pores in the PP matrix as revealed by SEM image is shown by means of histograms. Pore size distribution histograms were plotted by means of the porometric software of the Phenom desktop SEM, using number of pores (frequency) against pore size. The pore size distribution histograms for the selected samples are also shown in the bottom left side of Figs. 11 to 14. Beneath the histograms are shown the minimum and maximum pore sizes at the two extremes and the average pore size in the middle.

It can be seen from Figs. 11 to 14 that all the particle sizes and pore sizes detected were below 100 µm despite the fact that the filler particle sizes used in this research extended to 425 µm. This is because the ParticleMetric and PoroMetric Software can only detect particles and pores ranging from 100 nm to 100 µm.

It can also be seen in Fig. 11, that the unfilled PP had the smallest particles which are probably unintentional impurities. The largest particle size detected in the unfilled PP was 10.36 µm, the smallest particle size was 934.53 nm or 0.93453 µm, while the average particle size was 3.22 µm. Comparison of the particle size distribution detected in the filled PP (Figs. 12 to 14) and the unfilled PP (Fig. 11), shows that the minimum particle size detected was 3.27 µm, the maximum particle size was 92.52 µm while the average particle sizes ranged from 28.37 µm to 52.36 µm. Closer observation also reveals that the particle sizes detected are predominantly fine particles, evident from the cluster of the histogram towards the minimum particle size end, except with 425 µm where the particles were somewhat evenly distributed.
Similarly, it can be seen in Fig. 11, that the unfilled PP had the smallest pores probably due to lack of filler. The largest pore size detected in the unfilled PP was 18.52 µm² in area; the smallest pore was 0.18 µm² in area, while the average pore size was 0.73 µm². Comparison of the pore size distribution in the filled PP (Figs. 12 to 14) and unfilled PP (Fig. 11) shows that 0.18 µm² was the smallest pore size in all the samples.

The particle sizes and pore sizes detected were also found to increase with increase in particle size of the fillers investigated. These observations are in agreement with the fact that increasing the filler particle size implied enlarging the pore spaces in the matrix due to the difficulty of distributing coarse particles very well within the matrix and the poor interaction of the coarse particles.
Conclusions

Polypropylene-corn cob powder composites were successfully produced and the physical/end-use properties of the composites were determined. Results obtained showed that water sorption, flame propagation and solvent sorption were enhanced by increase in filler loading and particle size of the filler. Lower specific gravities were obtained as the composites were found to be lighter in weight than the unfilled (control) sample. It is hoped that this present study will help to place the usefulness of corn cob as filler in the compounding of thermoplastic in the plastic filler market in future and develop its niche in the scientific record.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.
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