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Effect of Filler Content and Particle Size on the Mechanical Properties of Corn Cob Powder Filled Recycled Polypropylene Composites

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Abstract

Composites of recycled polypropylene filled with corn cob powder were investigated for mechanical properties. The corn cobs were thoroughly cleaned, ground and sieved to three particle sizes of 150, 300 and 425 µm respectively. Filler loadings of 0 to 25 wt% were used in compounding the composites in an injection moulding machine and the resulting composites were extruded as sheets. Some mechanical properties such as tensile strength, flexural strength, yield strength, tensile modulus, elongation at break and hardness were determined. Results showed that incorporation of corn cob powder into the polymer matrix improved the tensile strength but had no significant improvement on flexural strength, tensile modulus and hardness of polypropylene composites. These properties were found to increase with filler loading but decrease with filler particle size. However, elongation at break was found to decrease with increasing filler loading. Highest tensile and flexural strengths were obtained at 15 and 20 wt% respectively at 150 µm particle size. It is therefore recommended that corn cob powder be used as filler in polypropylene.

Keywords: *Polypropylene, recycled polypropylene, corn cob, filler, composite, particle size.*

1. Introduction

In recent years, there is growing trend in the use of organic fillers in the manufacture of polymer composites due to their low density, low cost and non-abrasiveness (Cletus, 2002; Mengelogbu *et al*., 2000), possibility of high filling levels, high specific properties and availability (Abu-Sharch *et al*., 2004; Matuana *et al*., 1998).

Plastic wastes are one of the major components of global municipal solid waste and present a promising raw material source for composite production. Hence, the development of new value-added products, with the aim of utilizing agro and allied wastes and low cost recycled thermoplastics is assuming greater importance (Bavan & Kumar, 2010; Zurina *et al*., 2004).

Corn cob is the central core of an ear of maize (*Zea mays sp.*). It is part of the ear on which the kernels grow. Young ears, also called baby corn, can be consumed raw, but as the plant matures, the cob becomes tougher until only the kernels are edible. Apart from few identified applications of corn cob such as bedding for animals, use as biofuel and charcoal production, corn cobs are generally regarded as solid wastes and as such are seen dumped in dustbins within our localities (Engineers, 2006; Roth, 2014).

Some organic fillers have been reported as being effective fillers in polymers such as maize tassel (Onuegbu & Madufor, 2012), cocoa pod (Onuegbu *et al*., 2014), olive oil waste (Raid & Muhammad, 2015), saw dust (Saeed *et al*., 2005), rice husk (Zurina *et al*., 2004) and wood floor (Kokta *et al*., 1989). However, no investigation has been conducted on the application of corn cob powder in polymer composite materials. This paper therefore focuses on the potentials of using corn cob powder as filler in polymer composites. From the foregoing, the present work investigated the mechanical properties of polypropylene reinforced with corn cob powder.

2.0 Materials and Method

2.1 Materials

Polypropylene (PP) used in this research was a product of SK Global Chemicals Limited, Korea obtained from CeePlast Limited Aba, Abia State. Recycled polypropylene was sourced from Ihiagwa village, Owerri West L.G.A., Imo State and was thoroughly washed, dried and ground. Corn cobs were sourced locally from IyaluIbere, 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.

2.2. 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 25wt%) as shown in Table 1.

Table 1: Composition of Evaluated Formulations

Code	Virgin PP (g)	Recycled PP (g)	CC (wt%)
V (Control)	200	0	0
C_1	100	100	5
C_2	100	100	10
C_3	100	100	15
C_4	100	100	20
C_5	100	100	25

Each mixture was melted and homogenized with the filler in an injection moulding machine. To enhance compatibility, 7 g of maleic anhydride was added and the mixture was then extruded as sheets.

2.3 Testing

Tensile properties of each composite were determined according to standard (ASTM D 638) using a computerized universal testing machine (Instron Universal Tensometer, SSTM-Smart-1-Series-20KN; manufactured by Scientific Instrument Co. Ltd, U.S.A) at a crosshead speed of 5mm/min. Readings were recorded and calculated automatically by the instrument's software. Tensile properties obtained from this test are tensile strength, elongation at break, tensile modulus and yield strength.

Flexural strength was conducted according to standard (ASTM D 790) using Instron Universal Tensometer at a test speed of 2mm/min on a 3-point bending test. Loading was continued until fracture and values of flexural strengths were recorded automatically. Shore 'A' hardness was conducted in accordance with standard (ASTM D 2240) using a digital Durometer (JIS-K-6253). Readings were taken 10 seconds during the test period.

Morphological Analysis was also done 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.

3.0 Results and Discussion

3.1 Tensile Strength

Figure 1 shows the effect of corn cob contents on the tensile strength of the polypropylene composites compounded. The filled samples showed greater tensile strengths than the unmodified sample except for sample containing above 20 wt% filler. At any chosen filler particle size, tensile strength increased with increase in filler loading up to 15wt% before decreasing. The increase in tensile strength may be attributed to the strengthening effect of the filler incorporated into the polymer matrix. Fillers are usually added to polymeric materials to improve their rigidity and strength. The higher the content of filler incorporated, the stronger the polymer composite. Highest set of values were obtained at 15wt% filler loading.

However, excessive incorporation of filler may lead to filler agglomeration (weak bonding) in the polymer matrix leading to formation of microfiller due to the difficulties in achieving a homogeneous

dispersion of fillers. This results to stress concentration at the particle/matrix boundary region, leading to weakness of the particle/matrix interaction and consequent reduction in tensile strength. This may be responsible for the reduced strength as indicated for filler loadings of 20 wt% and above.

Also, it can be seen from Figure 1 that tensile strength decreased progressively with increase in particle size. It is an established concept that finer particles enhance the strength of a material. Finer particles provide larger surface area and this encourages better dispersion and interaction between the polymer matrix and filler particles. This consequently increases the ability of the composite to restrain gross deformation of the matrix. Highest set of values were obtained at 150µm particle size. Similar results were reported by Onuegbu and Madufor, (2012b), La Mantia and Morreale, (2006) and Atuanya, *et al*., (2014). Values obtained for tensile strength compared well with standard values (27 – 40 MPa) (John, 1992) and (31 – 41.4 MPa) (Calister & Rethwisch, 2010).

3.2 Flexural Strength

From Figure 2, the flexural strength of filled samples were lower than the unmodified sample. Flexural strength was found to increase with increase in filler content up to 15 wt% and increased with increase in particle size up to 300 µm followed by decrease at 425 µm particle size.

The increase in flexural strength could be attributed to the better rigidity and stiffness as a result of fair dispersion and distribution of the fillers in the polymer matrix, which efficiently hinders chain movement during deformation. Such an increase in flexural strength was reported by Atuanya *et al*., (2012), Embu *et al*., (2000), Das *et al*., (2002) and Tong *et al*., (2014).

3.3 Yield Strength

Results of yield strength are illustrated in Figure 3. Yield strengths obtained were found to be lower than the control. It could be observed that yield strength increased progressively with increase in filler loading up to 20 wt%, a behaviour similar to that of tensile strength. Above 20 wt% filler content, yield strength decreased. The increased yield strength may be as a result of the strengthening effect of the filler due to the fair dispersion in the polymer matrix.

3.4 Tensile Modulus

Results of tensile modulus are presented in Figure 4. Majority of the values obtained were lower than the control. Generally, tensile modulus was found to increase with increase in filler loading up to 15 wt% content and decreased with particle size. The highest set of values was obtained for 15 wt% content and at 150 µm particle size. Tensile modulus is an indication of the stiffness of a material. The incorporation of fillers into the polymer matrix improves the stiffness of the composites. This could be attributed to the fair distribution of the filler in the matrix, which efficiently hinders chain movement during deformation. On the other hand, smaller particles enhance better dispersion within the matrix than larger particles, hence the decreased tensile modulus with increase in particle size. Similar behaviour was also reported by Atuanya, *et al*., (2014), Onuegbu *et al*., (2014), Raid and Mohammad (2015) and La Mantia and Morreale (2006). However, Onuegbu and Igwe (2011) reported increase in tensile modulus with increase in particle size.

3.5 Elongation at Break

Figure 5 shows the effect of filler loading and filler particle size on the elongation at break of the polymer composites compounded. Lower elongations at break were recorded for the modified samples than for the unmodified. It is obvious from the data that elongation at break decreased steadily with increase in filler loading and particle size, with the highest set of values at 150µm particle size. Elongation at break is a reflection of the ductility of a material, a direct opposite of brittleness. Filler incorporation into a polymer matrix increased the stiffness and hardness of the composite. This increase in hardness resulted in decrease in ductility of the material. Hence, as filler content increases, the ductility decreases. Such decreasing elongation at break with filler loading was also reported by Sanadi *et al*., (1995), Nwanonenyi *et al*., (2013), Siti and Supri (2009) and Onuegbu and Igwe (2011).

3.6 Hardness

Figure 6 shows the result for hardness obtained in this research. Hardness of the modified samples were

all higher than the unfilled samples. The results obtained showed increased hardness with filler loading but decreased values with particle size. This is attributed to the fact that these fillers act as reinforcing fillers. Incorporation of the fillers into the polymer matrix enhanced the stiffness of the material. The higher the percentage of the fillers incorporated, the harder the material, and the more rigid it becomes. This is evident even from the results obtained for elongation at break, a direct opposite of hardness, which was noticed to decrease with increase in filler content. Atuanya, (2014) and Atuanya *et al*., (2014b) reported similar increase of hardness with filler loading while Onuegbu and Igwe (2011) and Kokta *et al*., (1989) reported decreased value with particle size.

The morphological analysis of the some selected composites was done using Scanning Electron Microscope and the micrographs are showed in Figures 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 due to interaction with each other. This resulted to creation of pores in the system as could be observed in micrographs at 415 µm (Figures 10).

Conclusion

The mechanical properties of corn cob filled recycled polypropylene composites were studied in this research. The tensile strengths of the composites were found to be higher than that of the unmodified sample. Other mechanical properties studied were found to be lower for the filled composites than for the unfilled. Tensile strength, flexural strength, tensile modulus and hardness were found to increase with increase in filler loading up to 15 wt% while elongation at break decreased with increase in filler loading. The properties were also found to decrease with increase in filler particle size. It is therefore recommended that corn cob powder be used as filler in polypropylene composites.

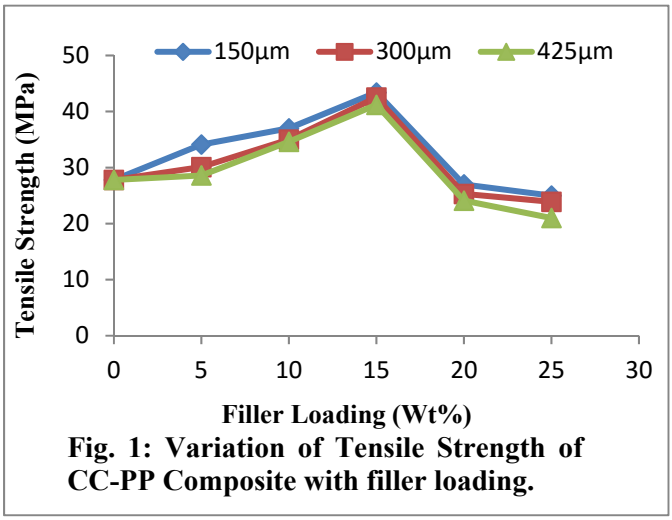

Fig. 1: Variation of Tensile Strength of CC-PP Composite with filler loading.

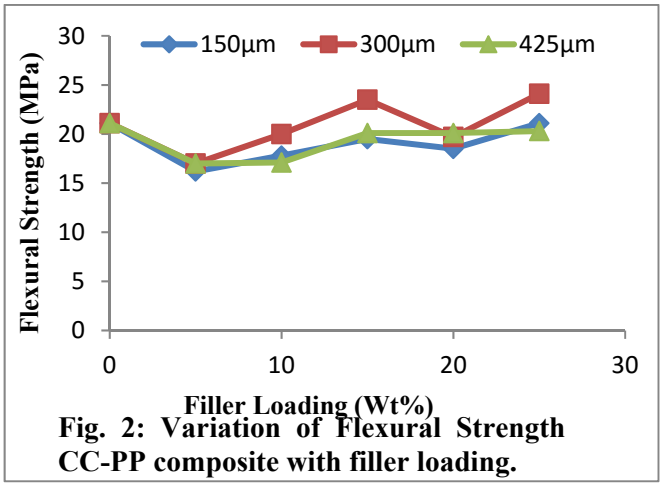

Fig. 2: Variation of Flexural Strength CC-PP composite with filler loading.

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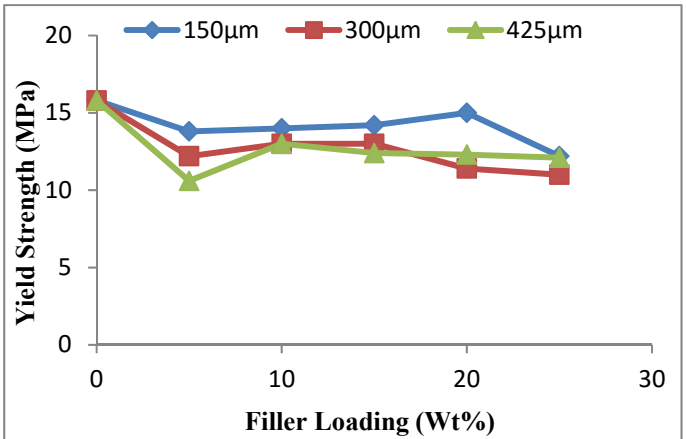

Fig. 3: Variation of Yield Strength of CC-PP composite with filler loading.

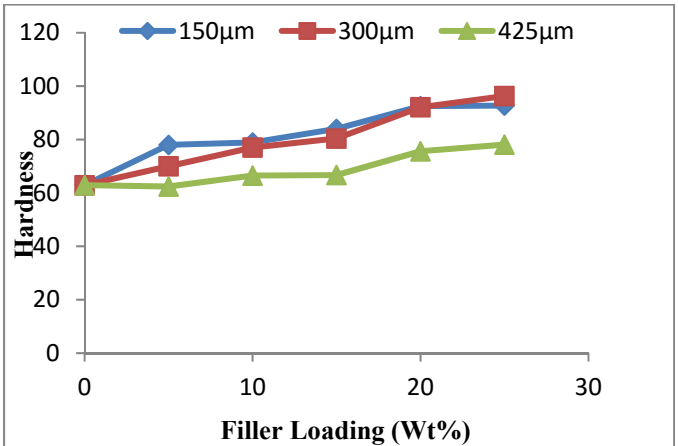

Fig. 6: Variation of Hardness of CC-PP composite with filler loading.

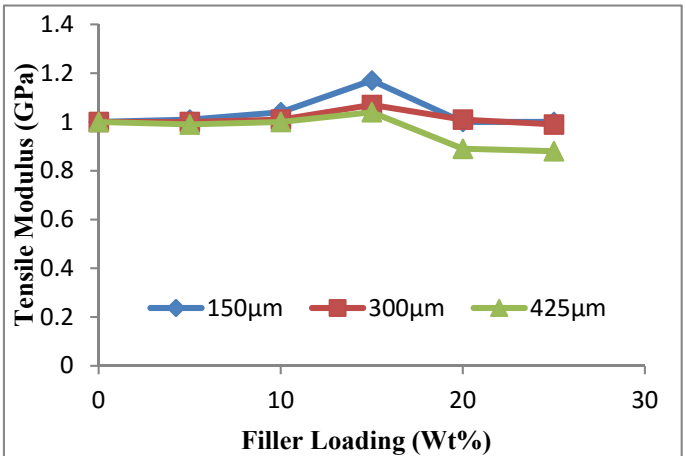

Fig. 4: Variation of Tensile Modulus of CC-PP composite with filler loading.

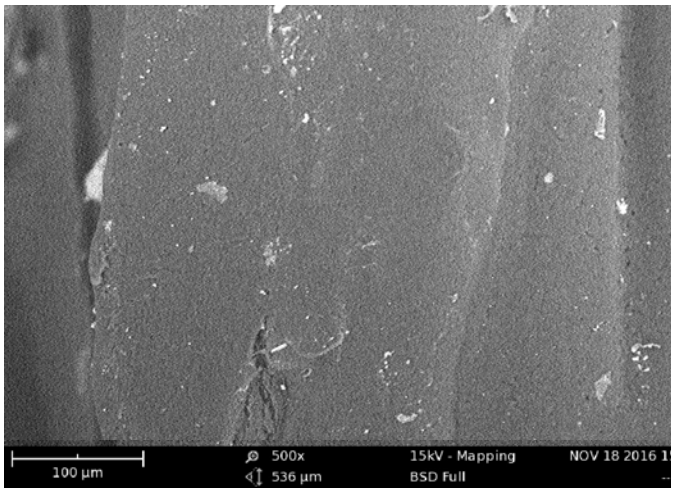

Fig. 7: SEM Micrograph of the control experiment.

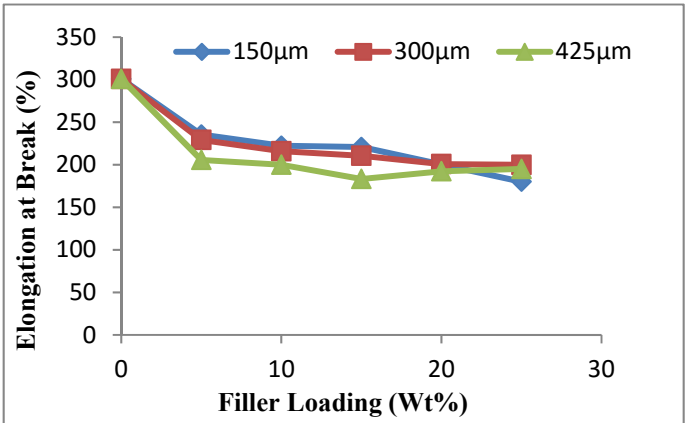

Fig. 5: Variation of Elongation at Break of CC-PP composite with filler loading.

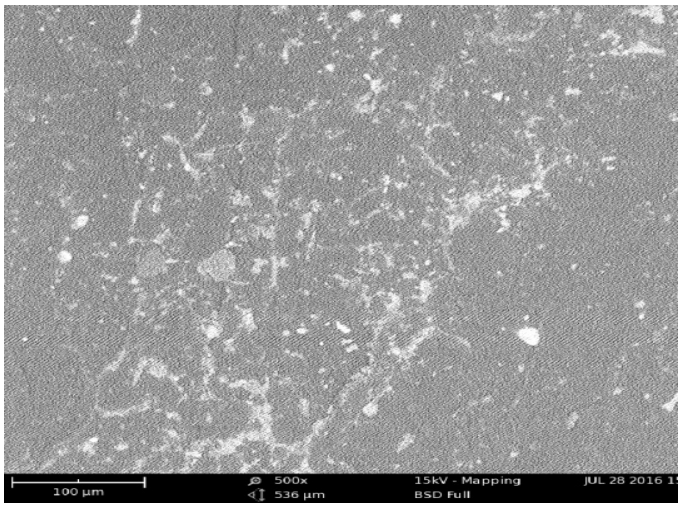

Fig. 8: SEM Micrograph at 15 wt% filler loading and 150 µm particle size.

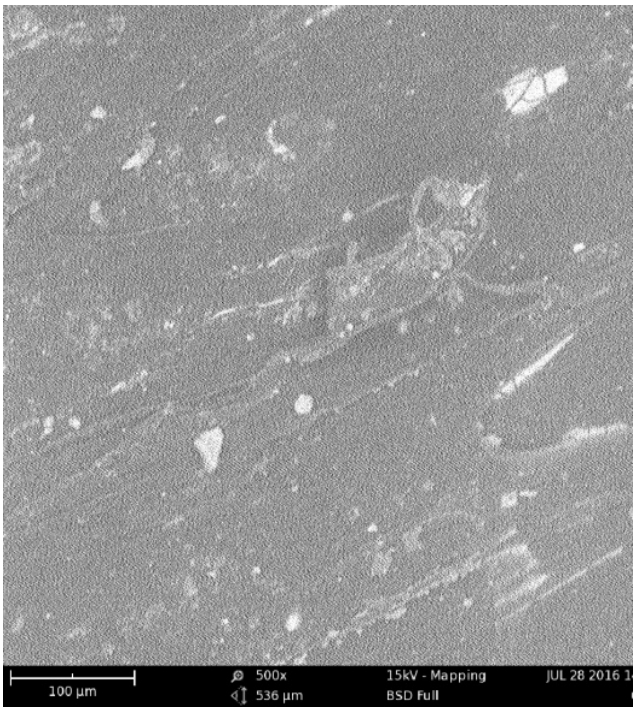

Fig. 9: SEM Micrograph at 15 wt% filler loading and 300 µm particle size.

Fig. 10: SEM Micrograph at 15 wt% filler loading and 425 µm particle size.

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