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PRODUCTION OF UNIFORMLY DISPERSE CARBON NANOTUBE/HIGH DENSITY POLYETHYLENE NANOCOMPOSITE USING NOVEL NANOFEEDER INJECTION MOULDING MACHINE

S. GADIMOH[1*], H. D. IBRAHIM[2], E. G. KOLAWOLE[3], NKEONYE, P.O.[4], MUSTAPHA A.[5]
*National Research Institute for Chemical Technology, Basawa, Zaria.[1,]
Raw Materials Research and Development Council, Abuja.[2,5]
Department of Chemistry, Bowen University, Iwo, Osun State[3]
Dept. of Textile Science and Technology, A.B.U., Zaria.[4]
[sgadimoh@gmail.com]

ABSTRACT
Uniformly disperse single-walled carbon nanotube (SWCNT)/High density polyethylene (HDPE) nanocomposite has been produced using the developed nanofeeder injection mould machine. The dispersion state of SWCNTs in the HDPE matrix was evaluated by transmission electron microscope and Atomic force microscope images and confirmed with conductivity test. It was found that the dispersion state of SWCNTs was better in the samples produced with the nanofeeder injection moulding machine for all concentrations of SWCNTs. This nanofeeder injection moulding machine developed can be adopted in the mass production of uniformly dispersed nanocomposite which is relevant in the area such as optical displays, catalysis, photovoltaics, gas sensors, electrical devices, mechanics, photo-conductors and superconductor devices.

Keywords: *Single-walled carbon nanotube, percolation threshold, dispersion state, injection moulding machine, nanocomposite, nanofeeder.*

1.0 Introduction

Polymer composites are manufactured commercially for many diverse applications such as sporting goods, aerospace components, automobiles, etc. In the last 20 years, there has been a strong emphasis on the development of polymeric nanocomposites, where at least one of the dimensions of the filler material is of the order of a nanometer. The final product does not have to be in nanoscale, but can be micro- or macroscopic in sizes (Ayman, E., 2005).

In melt processing, carbon nanotubes are mechanically dispersed into a polymer melt (prepared by heating) using a mixer or a compounder (Andrews R. et al., 2002). The main idea is to use fluid shear forces to break nanotube aggregates or prevent their formation. This approach is simple and compatible with existing polymer processing techniques such as extrusion, injection moulding and compression moulding.

'The properties of nanocomposite materials depend not only on the properties of their individual parents but also on their morphology and interfacial characteristics, (Oriakhi, C.O, 1998). This morphology and interfacial characteristics are more often than not dictated by the dispersion of the CNT in the matrix.

Production of nanocomposite with well dispersed nanotubes and low percolation threshold using existing/traditional compounding techniques is very difficult due to the strong tendency of the nanotubes to agglomerate, and where it is achieved, more often than not at high weight%, there is possibility of splitting of agglomerate nanotubes in the nanocomposite when subjected to force. Therefore, premature failure takes place in the final product and electrical conductivity is often not attainable (Haggenmueller, R., et al. 2006). To improve dispersion, percolation and compatibility in polymer matrices, nanotubes are being functionalized (Haggenmueller R, et al. 2003). But the processes of functionalizing the nanotube more often than not affect the properties of the nanotubes and hence that of the final product (Wang, Y., et al., 2007).

In this work, High density polyethylene (HDPE) was compounded with single-walled carbon nanotubes (SWCNT) using a patented nanofeeder injection moulding machine (Gadimoh, S., et al 2015). The samples produced were analyzed to determine the dispersion state of the SWCNT in the HDPE. The techniques used by the machine is that of nanofeeding and double shear mixing, the system consists of a three nanofeeder extruder coupled to an injection moulding machine (Gadimoh, S., et al 2015). The main objective of this paper is to test the effectiveness of the nanofeeder injection moulding machines developed for the production of well dispersed nanocomposite, to find solution to the lingering problem of dispersion of nanotubes in the compounding of nanocomposite.

2.0 Materials and Methods

2.1 Materials

The HDPE with an average molecular weight (Mw) of 60,000 g/mol used in this work was obtained from Eleme Petrochemical Company Port Harcourt, Nigeria, and the 60% singlewall carbon nanotube (SWCNT) was purchased from Carbon Solution Inc. CA, USA. All the materials were used as received. The nanocomposite was produced with the nanofeeder injection moulding developed by the Author. All the anaylsis, which include AFM, TEM, and Electrical conductivity test were all conducted in Zhenjiang University China.

2.2 Methods

Control specimen (only the HDPE matrix) was first produced, and then various concentrations of 0.2, 0.4, 0.6, 0.8 and 1wt% of SWCNT were produced to ASTM D638 standard tensile bars.

2.2.1 Morphological Analysis and Dispersion Evaluation of CNTs in the Samples

Transmission Electron Microscope (TEM) (JEOL, JEM-2100 F) was used to observations and study the CNTs dispersion in HDPE matrix. Atomic Force Microscope (AFM, Nanoscope IIIa) was operated in the tapping mode, provided with tips of average radius of 10 nm and applying moderate forces (typically amplitude set points between 0.8 and 2 V and drive amplitudes of 50 to 500 mV). Scan rates were in the range of 0.8-1.2 Hz.

2.2.2 Electrical Conductivity

Electrical conductivity of CNT-HDPE films loaded with different weight fractions (0.2–0.1wt%) of SWCNTs was measured at room temperature using a Fluke electrometer (3Fluke 1550B MegOhmMeter, Fluke Corporation, Everett, Washington). The electrometer is capable of measuring DC electrical resistance up to 1 TΩ. DC volumetric resistance (R) was measured using two silver paint electrodes of 5 mm length painted on the film edges of 25 mm long specimens, leaving an effective span (L) of 15 mm between the silver electrodes, [8]. Specimen width was 6 mm and film thickness ~150–200 μm. In order to reduce surface effects in the measurements, silver paint electrodes were painted completely covering the ends of the sample. A DC voltage was applied through the length of the specimen and the conductivity (σ) was calculated using

Equation (1): $\sigma = L / AR$

Where; A is the cross sectional area of the sample and R the measured electrical resistance. The results are shown and discussed in section 3.3.

Ten specimens of each compounding were produced, making a total of sixty (60) specimens.

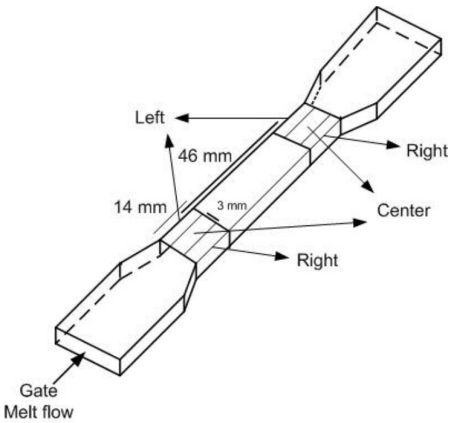

Figure 1: ASTM D638 Standard Tensile bar specimen

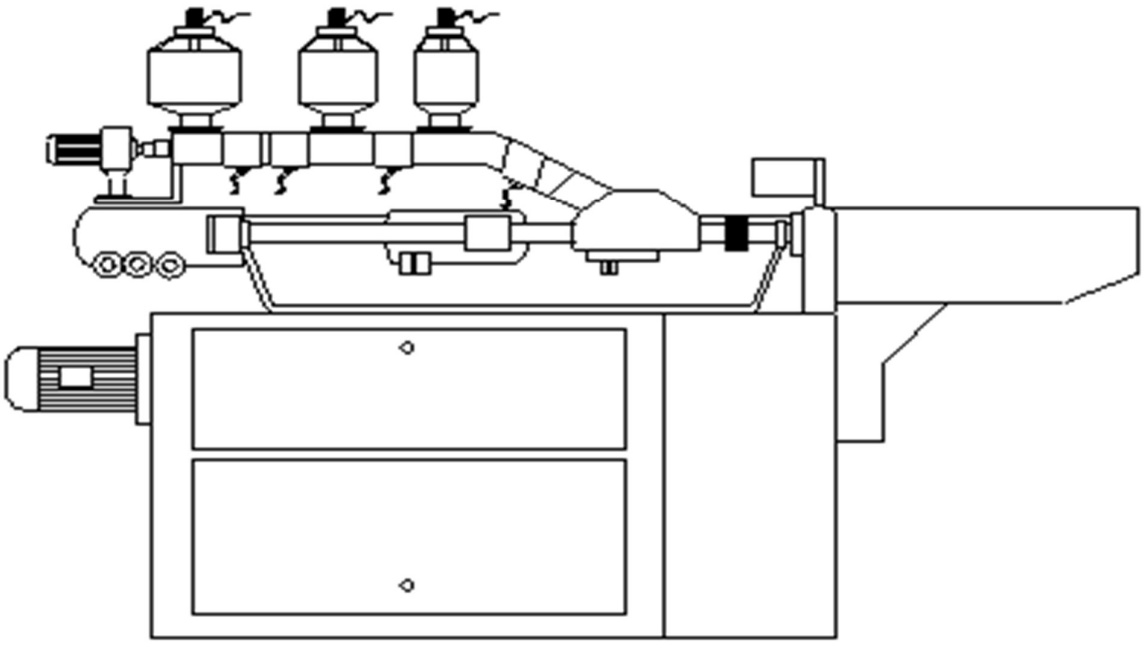

Figure 2: Drawing of nanofeeder injection moulding machine.

Plate 1: The Nanofeeder Injection Moulding Machine.

3. Results and Discussion

3.2 Dispersion Evaluation of the nanocomposite samples

The nanotubes alignment and distribution were observed by AFM, as shown in the figures below.

As can be seen from the AFM images, the samples were uniform throughout. This can be attributed to the uniform nanofeeding and the double shear mixing of the nanofeeder injection moulding machine. This implies that the developed machine can be adopted for the mass production of nanocomposite products of the same properties which is difficult to achieve with present available production systems.

The AFM images above A1, A2, A3 and A4 also shows well dispersion of the nanotubes in the polymer matrix, possibly because the machine actually prevented the formation of agglomeration of the CNTs, this was achieved due to the fact that the CNTs were fed in nano wise by the automated nanofeeder into the extrusion barrel where initial shear mixing is done after which it is fed into the injection barrel where further shear mixing is done before it is then injected into the mould. This ensures a well dispersed CNT/HDPE nanocomposite as evident in the AFM image of Figure 3. The AFM images further seem to suggest that there could be better lower percolation threshold in the samples.

The lowest nanotube loading 0.2wt% was selected for the TEM imaging since percolation seems to be form for all samples as shown in the AFM studies above. The TEM study of the 0.2wt% nanotube loading gave evidence of the existence of a nanotube–polymer network in the SWNT/HDPE nanocomposites, which will certainly give rise to percolation.

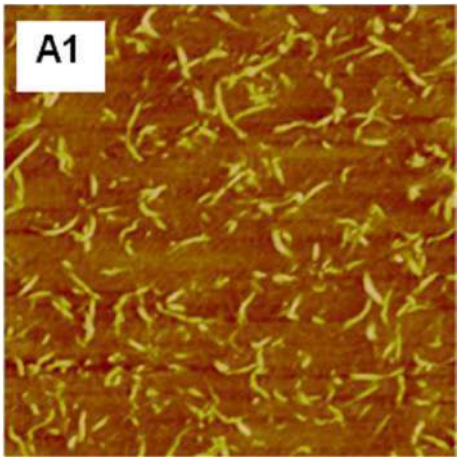

Figure 3: AFM images of the 0.2wt%,

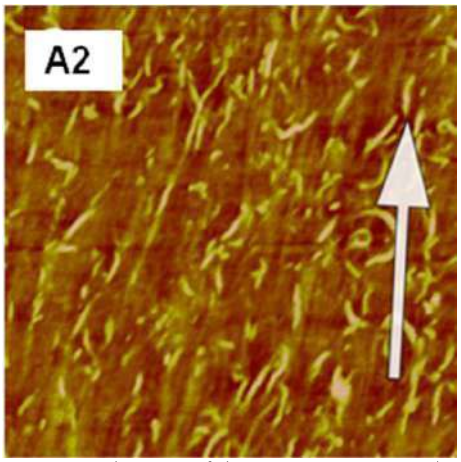

Figure 4: AFM images of the 0.4wt%, SWCNT/HDPE nanocomposite sample A2.

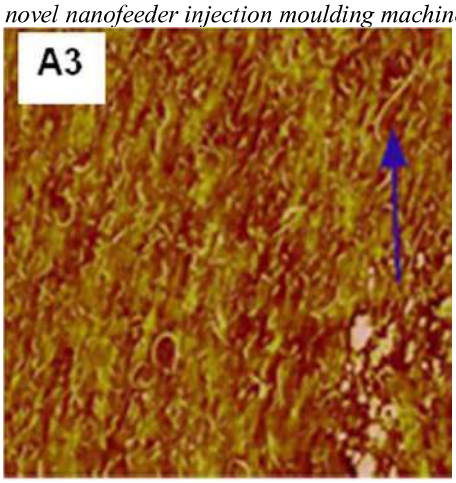

Figure 5: AFM images of the 0.6% SWCNT/HDPE nanocomposite sample A3.

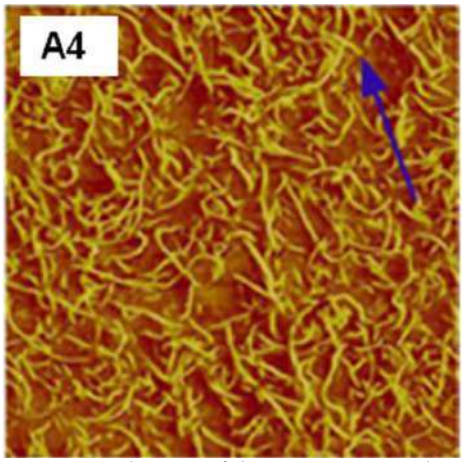

Figure 6: AFM images of the 1wt% SWCNT/HDPE nanocomposite sample A4.

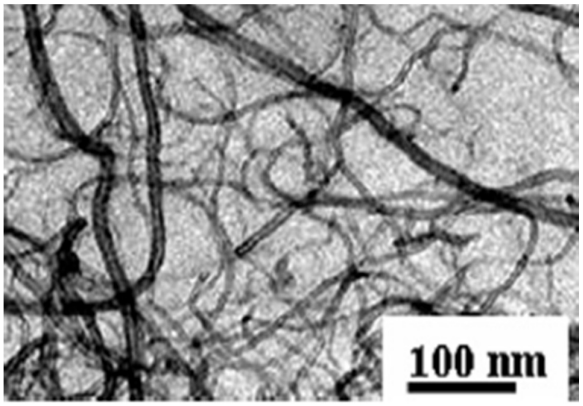

Figure 7: TEM image of 0.2wt% SWCNT/HDPE Nanocomposite studied at 100nm

3.3 Electrical Conductivity

Figure 5 shows electrical conductivity of the composite films as a function of weight loading for the samples. Overall, electrical conductivity was observed in all the samples tested, thus indicating the formation of a percolation network in all the samples as shown in the AFM and TEM studies.

The conductivity of samples increases with nanotube loading up to 0.6wt% after which the conductivity remain constant throughout up to 1wt% loading. The increase in conductivity due to increase in nanotube loading in the samples may be related to the increased CNT-to-CNT contact/junctions in the samples.

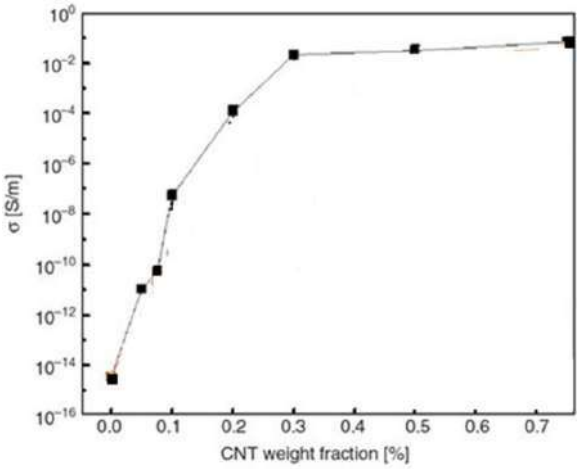

Figure 8: Electrical conductivity vs. CNT weight fraction (%) loading for all the samples tested.

4. Conclusion

The nanofeeder injection moulding machine developed and already patent was used for the production of carbon nanotube/HDPE nanocomposite. The various studies conducted on the samples reveals that the samples produced exhibit a relatively much better dispersion of SWCNTs in the Matrix which gave rise to low percolation and hence conductivity at samples with lower wt% nanotube loading compare to those found in our literature survey. This implies that this method of production can be adopted in the mass production of uniformly dispersed nanocomposite which is relevant in the area such as optical displays, catalysis, photovoltaics, gas sensors, electrical devices, mechanics, photo-conductors and superconductor devices.

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