MECHANICAL AND ELECTRICAL PROPERTIES OF BISMUTH FILLED HIGH DENSITY POLYETHYLENE COMPOSITES

Sheela M[1,2], Vinayak Anand Kamat[4], Eshwarappa K M[3,5],

[1]Assistant Professor, Department of Physics, Government Science College, Hassan, Karnataka, India
[2] Research scholar, Bharathiar University, Coimbatore, Tamil Nadu, India
[3]Research supervisor, Bharathiar University, Coimbatore, Tamil Nadu, India
[4]Research scholar, CARRT, Mangalore University, Mangalore, Karnataka, India
[5]Department of PG Studies and Research in Physics, Government First Grade College, Holenarasipura, Karnataka, India

ABSTRACT

Effect of bismuth filler on mechanical and electrical properties of High Density Polyethylene (HDPE) is described in this study. HDPE composites with different weight percentage of bismuth (0%, 10%, 20% and 40%) were fabricated by using hydraulic press. The mechanical properties like tensile strength, tensile modulus and the elongation at the peak load were studied by using universal testing machine (UTM), impact strength was determined using computerized impact tester and density of the composites were estimated on Archimedes principle. The dispersion of the filler in HDPE was studied using scanning electron microscope (SEM). The density of HDPE has been observed to increase with increase in bismuth concentration. The value of tensile strength and Young's modulus of HDPE become maximum at 10 wt% of bismuth loading and then decreases at 20 wt% of bismuth with HDPE. However, the slight increase in the tensile strength and Young's modulus is observed beyond 20 wt% of bismuth with HDPE. The elongation and impact strength decreases with the increase of bismuth concentration in HDPE. The electrical properties like dielectric constant, dielectric loss, AC conductivity and impedance were studied for synthesized composites using LCR meter for the frequency range 100Hz-1MHz. The dielectric constant increases with the increase in weight percentage of bismuth with HDPE and then slightly decreases for higher frequencies. The AC conductivity increases sharply at higher frequencies but is of very low value ($10^{-10}Sm^{-1}$). The dielectric loss and the impedance decreases with frequency.

Keywords:- *Bismuth, HDPE, tensile strength, tensile modulus, impact strength, dielectric properties, impedance, AC conductivity.*

---

1. INTRODUCTION

HDPE is known for its greater strength among other polymers. Although the density of HDPE is marginally higher than the other polymers, it has strong intermolecular forces, tensile strength, low moisture absorption chemical and corrosion resistance properties. This polymer has density 0.920 gm/cm^3. Bismuth is a naturally occurring heavy element with atomic weight 83 and atomic mass 209 and high density of 9.8 gm/cm^3. The aim is to study the variation in mechanical properties like density, tensile strength, tensile modulus, impact factor, elongation at the peak and also to study electrical properties like dielectric constant, dielectric loss, AC conductivity and impedance of HDPE when bismuth is added in different weight percentage (0%, 10%, 20%, and 40%) for further study of gamma shielding properties of these composites.

Many researchers have studied the changes in the mechanical and electrical properties of different polymer matrix filled with different fillers. B. Narayanaswamy et al. (2017) investigates the effect of chemical treatment on the physical and mechanical behavior of coconut shell powder and lime stone powder as fillers in different wt% (5%, 7.5% and 10%) reinforced with HDPE matrix. From the study it is observed that the tensile strength of the composite is maximum at 5 wt% of lime stone composite, flexural strength and impact strength of the composites are found to be maximum at 10 wt % of lime stone composite [1]. Daniel Eirasa et al., (2009) evidenced the influence of calcium carbonate nano particles with different weight percentage (3%, 5%, 7% & 10%) on the mechanical properties of polypropylene. The elastic modulus and yield stress increased with the increase in the addition of calcium carbonate nano particles [2]. Han-Seung Yang et al., (2004) studied the tensile strength and tensile modulus of rice husk filled polypropylene composites, which increase with filler w% and also it is noticed that the composites become brittle at high cross head speed and plastic deformation increases with test temperature [3]. In a study conducted by Iftekhar Ahmad et al. (2010), evidence that, the enhancement in the value of tensile strength and relative elongation for HDPE filled with smallest size fly ash particles. It is also noticed that the tensile modulus and impact resistances are not much dependent on particle size of fly ash fillers [4]. Moayad N. Khalaf, (2015) studied lignocellulose filled HDPE can possess appreciable mechanical strength compared with other fillers [6]. Qingfa Zhang et al., (2018) performed the effect of addition of rice husk biochar/plastic composites to HDPE on mechanical property, in which it was noticed that, with the increase of filler content BPC (biochar/plastic composites) are better than WPC (wood plastic composites) [8].

Waleed A Hussain et al., (2015) found the dielectric constant, dielectric loss and the loss tangent for epoxy/alumina silicate composites increases with the increasing alumina silicate NGK (insulator part as a filler) filler content [10]. As per Dillip K Pradhan et al., (2008) the dielectric relaxation and AC conductivity increase with the increase in plasticizer concentration in plasticized polymer nano composite electrolytes (PPNCEs) [11]. Hence, in the present study an attempt is made to study the effect of bismuth on mechanical and electrical properties of HDPE polymer, and further study on gamma shielding properties of these composites is to be carried out.

2. MATERIALS AND METHODS

2.1 Preparation of samples

The thermoplastic HDPE (injection grade) was selected as the base polymer matrix and it was purchased from Banu plast, Mumbai and the pure bismuth filler was purchased from Sarda Industrial Enterprises, Jaipur, Rajasthan.

The composites were developed by mixing HDPE powder with density 0.920 gm/cm^3 mixed thoroughly with four different weight percentage (0%, 10%, 20%, 40%) of bismuth powder having the density of 9.8 gm/cm^3 by mechanical mixing method. The HDPE-bismuth mixture was taken into the mould with size of 30 cm x 30 cm x 0.3 cm and placed in the hydraulic press at the temperature of about 180 ^{O}C with the load pressure of 1000 kg for about 10 minutes and then the machine was allowed to turn off. The applied load was released after the temperature of the hydraulic press falls to 80^{O}C-90^{O}C. HDPE/Bi composites were then removed from the mould and were then cut into required dimension for the further characterization. The samples are as shown in the fig1.

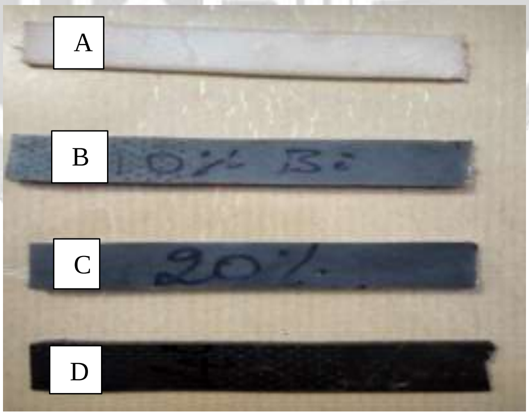

Fig-1: Samples- A) Pure HDPE polymer
B) 90% HDPE + 10% bismuth
C) 80% HDPE + 20% bismuth
D) 60% HDPE + 40% bismuth

2.2 Homogeneity test

The surface morphological and homogeneity of the samples were tested by using scanning electron microscope (JSM IT 300) at applied voltage of 15 kV 1000X resolution.

2.3 Mechanical studies

The mechanical properties of polymer composites such as tensile strength, tensile modulus, and elongation at the peak were studied using universal testing machine (UTM). The rectangular shaped test specimen with dimension 36 sq. mm was used for tensile measurement. Sample was placed between the grips of the UTM and was pulled at the speed of 50 mm/min until it breaks due to the application of load. The impact strength of the specimen was determined by using computerized Impact tester.

2.4 Electrical properties

The AC electrical conductivity and the dielectric properties of HDPE/Bi composites with dimension of 20 mm x15 mm x 2.5 mm were studied by using LCR meter in the frequency range 100 Hz -1 M Hz at 30°C for 1 V. The dielectric constant (ε'), dielectric loss (ε'') and AC conductivity (σ_{ac}) of the synthesised HDPE+Bi composites were calculated by using the following equations (Hussain, W.A. et al., 2019).

$$\varepsilon' = C_p\, d/\varepsilon_0 A \qquad - (1)$$

$$\varepsilon'' = \varepsilon' \tan\delta \qquad - (2)$$

$$\sigma_{ac} = \varepsilon'\varepsilon_0 \omega \tan\delta \qquad - (3)$$

The dissipation factor D = tan δ= cot θ= 1 / (2πfRpCp), where δ is the loss angle, θ is the phase angle, f is the frequency, Rp is the equivalent parallel resistance, and Cp is the equivalent parallel capacitance, d is the thickness and A is the area of the sample, ε_0 is the permittivity of the free space, ω is the angular frequency.

The complex impedance can be expressed as Z*= Z + i Z', where Z' is the imaginary part of the impedance, Z is the real part of the impedance at different frequencies up to 1MHz. It was measured by Impedance Analyzer.

3. RESULTS AND DISCUSSION

3.1 SEM test

The dispersion of bismuth over the surface of synthesized HDPE composites was examined by using scanning electron microscope (SEM). The SEM image of pure HDPE shows (Fig 2a) the presence of graded ridges and it can cause low mechanical properties compared to HDPE/Bi composites. On addition of 10 wt% of bismuth to HDPE the number of ridges has reduced (Fig 2b). A nonhomogeneous distribution of bismuth particles in HDPE matrix was observed with 20 wt% of bismuth loaded HDPE composites (Fig 2c) and this resulted in decrement of tensile strength and tensile modulus (Iftekhar Ahmad et al., 2010). Fig 2d shows the uniform distribution of the 40 wt% of the filler in HDPE matrix.

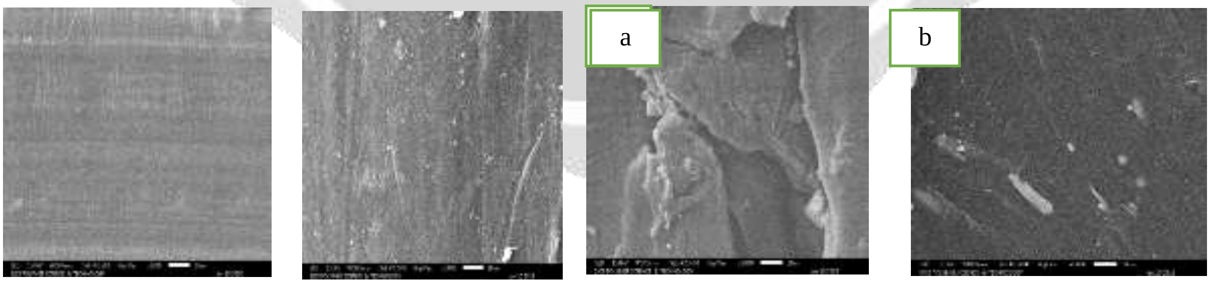

Fig-2: SEM images a) HDPE b) HDPE+10% bismuth c) HDPE+20% bismuth d) HDPE+40% bismuth

3.2 Mechanical properties

A. Density

Archimedes principle has been used to determine the density of the prepared composites. From the Fig 3 it is observed that the density of the HDPE has increased with increase in bismuth concentration. This trend is observed due to presence of high density of bismuth (0.92 gm/cm^3 to 1.29 gm/cm^3) fillers.

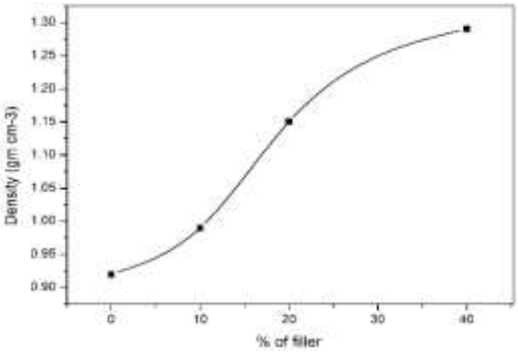

Fig-3: Effect of bismuth on density of HDPE

B. Tensile test

Variation in tensile strength of bismuth loaded HDPE composites is shown in the Fig. 4. It has been observed that there is an increase in tensile strength when HDPE is filled with 10 wt % of bismuth. However, further addition of bismuth at 20 wt% of bismuth leads to decrease in tensile strength. The initial increase and decreasing behaviour in tensile strength of synthesized composites was observed mainly due to surface contact area and nonhomogeneous distribution of bismuth particles at 20 wt% of bismuth added to HDPE. Beyond 20 wt% of bismuth concentration, the increment in tensile strength is observed for synthesized composites due to the homogeneous distribution of bismuth with HDPE (Fig. 2c). The variation in Young's modulus is also similar to tensile strength as shown in Fig. 5. The elongation at peak load of prepared HDPE composites has shown decreasing trend with increase in bismuth weight percentage (Fig. 6) and this can be ascribed to loss in flexibility of HDPE with increment in filler loadings (Moayad N. Khalaf 2015).

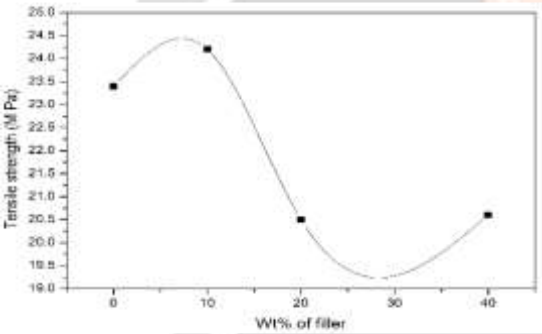

Fig-4: Effect of bismuth on tensile strength of HDPE

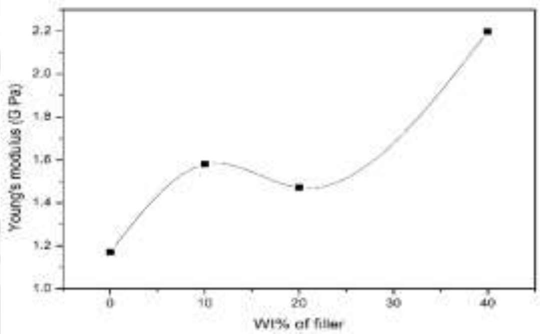

Fig-5: Effect of bismuth on young's modulus of HDPE.

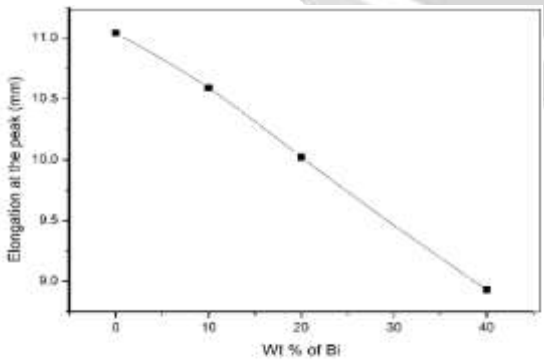

Fig-6: Effect of bismuth on elongation at the peak of HDPE

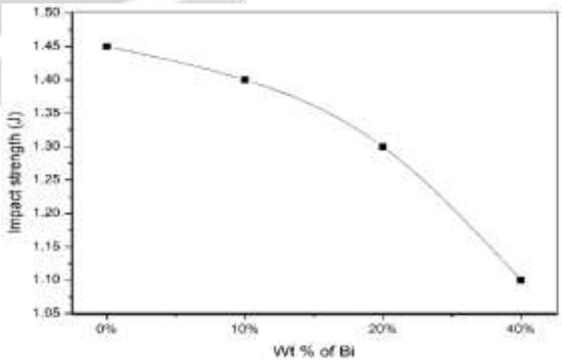

Fig-7: Effect of bismuth on impact strength of HDPE

C. Impact test

Impact strength of HDPE is decreased with the addition of bismuth to HDPE as shown in Fig. 7. This observation is due to decrement in flexibility of the composite with addition of high density bismuth to HDPE matrix. The material can easily break by the application of external forces at the bismuth and HDPE interface due to weak interaction between them and thus the impact strength of the composites decreases with increment in wt% of bismuth (X-L Wang et al., 2015).

3.3 AC conductivity

The electrical properties were studied by using LCR meter shows that the dielectric constant of the samples increases with the increase in weight percentage of the filler and then slightly decreases with increase in AC frequency as shown in the Fig. 8. This may be due to the fact that the dipolar polarization of HDPE matrix and the interfacial polarization of the HDPE/Bi composites become less in the direction of alternating field at high frequencies. All the samples have shown almost same value of dielectric loss and it decreases with increase in frequency. At higher frequencies the dielectric loss becomes constant as shown in the Fig 9. Fig. 10 shows the AC conductivity remains constant at low frequency and increases sharply with a very narrow range of frequencies in all samples. This may be due to the formation of the conducting phase by the Bismuth filler particle. Fig. 11 shows the decrease in impedance of the sample with increase in bismuth wt % in HDPE composites and with increase in frequency of AC. This is due to the increasing of interfacial polarization (Hussain et al., 2015: Dillip K. Pradhan et al., 2008). Thus the bismuth filled HDPE composites exhibited good dielectric property.

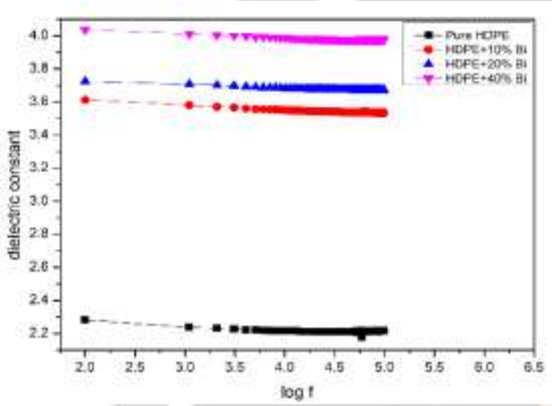

Fig-8: Variation of dielectric constant w r t frequency.

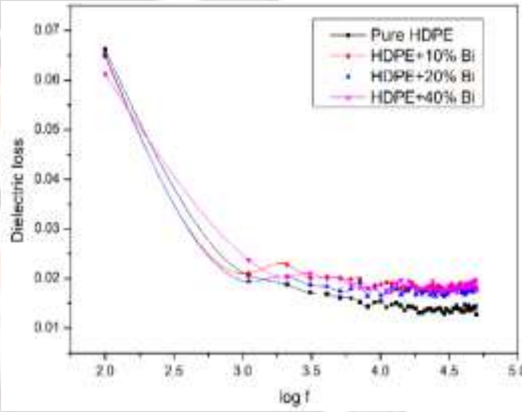

Fig-9: Variation of dielectric loss w.r.t frequency

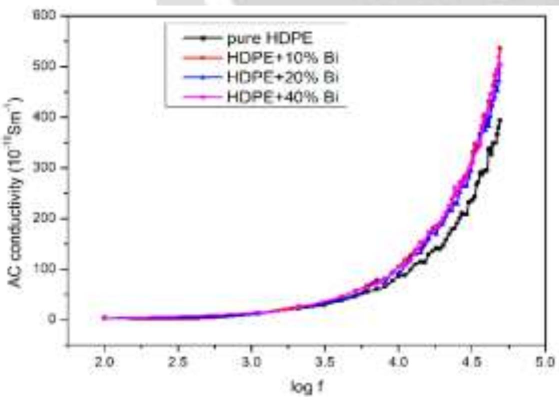

Fig-10: Variation of AC conductivity w.r.t frequency

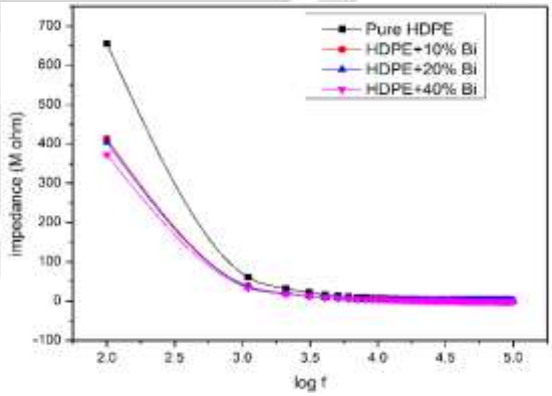

Fig-11: Variation of Impedance w.r.t frequency

4. CONCLUSION

In this study pure bismuth filled HDPE composites were fabricated and their mechanical and electrical properties were analyzed. It was found that bismuth was distributed uniformly within the HDPE matrix. A non-uniform dispersion of the bismuth particles is observed at 20 wt% of bismuth concentration and it tends to decrease in its tensile strength and Young's modulus. Hence, from the present study it is observed that 10 wt% of bismuth is the optimum percentage to be loaded to HDPE to get maximum strength. The dielectric studies and the AC conductivity measurements show that bismuth filled HDPE polymer composites show the sharp increase in ac conductivity at higher frequencies but are of very low value (10^{-10} Sm^{-1}). The value of dielectric constant is observed to increase with the filler weight percentage. The dielectric loss and the impedance of the samples were found to decrease with the frequency. This concludes that the bismuth filled HDPE composites are good dielectrics.

5. ACKNOWLEDGEMENT

The authors are thankful to Dr; Siddaramaiah, Head of the Department of Polymer Science, Sri Jayachamarajendra College of Engineering, Mysore for supporting us in the preparation of the samples and mechanical property studies.

6. REFERENCES

1. Narayana Swamy B, Suresh Babu Y, Tirupati Reddy K, "Mechanical properties of HDPE polymer composites", International Journal of Engineering Science and Computing, January 2017.
2. Daniel Eirasa, Luiz Antonio Pessanb, "Mechanical Properties of Polypropylene/Calcium Carbonate Nanocomposites", Materials Research, Vol. 12, No. 4, 517-522, 2009.
3. Han-Seung Yang, Hyun-Joong Kim, Jungil Son, Hee-Jun Park, Bum-Jae Lee, Taek-Sung Hwang, "Rice-husk flour filled polypropylene composites; mechanical and morphological study", Composite Structures 63 (2004) 305–312.
4. Iftekhar Ahmad and Prakash A. Mahanwar, "Mechanical properties of fly ash filled high density polyethylene", Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.3, pp.183-198, 2010.
5. Maged A. Osmanand, Ayman Atallah, "Surfactant chain length and tensile properties of calcium carbonate-polyethylene composites", Macromolecular Chemistry and Physics, vol. 208, no. 1, pp. 87– 93, 2007.
6. Moayad N. Khalaf, "Mechanical properties of filled high density polyethylene", Journal of Saudi Chemical Society (2015) 19, 88-91.
7. Ambika M. R., Nagaiah N., Krupashankara M.S., "Study of mechanical strength of polyester-bismuth oxide polymer composites", IJARIIE-ISSN(O)-2395-4396, Vol-2 Issue-1 2016. Vol-1 Issue-5 2016 IJARIIE-ISSN (O)-2395-4396.
8. Qingfa Zhang, Weiming Yi, Zhihe Li, Lihong Wang and Hongzhen Cai, "Mechanical properties of rice husk biochar reinforced high density polyethylene composites", Polymers 2018, 10, 286.
9. Dillip K. Pradhan, Choudhary R. N. P., Samantaray B. K., "Studies of Dielectric Relaxation and AC Conductivity Behavior of Plasticized Polymer Nanocomposite Electrolytes", Int. J. Electrochem. Sci., 3 (2008) 597 – 608.
10. Waleed A. Hussain, Abdullah A. Hussein, Jabar M. Khalaf, Ali H. Al-Mowali, Abdullwahab A. Sultan. "Dielectric Properties and a.c. Conductivity of Epoxy/Alumina Silicate NGK Composites", Advances in Chemical Engineering and Science, 2015, 5, 282-289.
11. X-L Wang, H Ming and H Yin, "Fabrication and properties of HDPE/CF/CaCO3/PE-g-MAH quaternary composites", IOP Conf. Series: Materials Science and Engineering 87 (2015) 012110.