

Research Article

Thermal Effect of Ceramic Nanofiller Aluminium Nitride on Polyethylene Properties

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Ethylene polymerization was done to form polyethylene nano-composite with nanoaluminum nitride using zirconocene catalysts. Results show that the catalytic activity is maximum at a filler loading of 15 mg nanoaluminum nitride. Differential scanning calorimeter (DSC) and X-ray diffraction (XRD) results show that percentage crystallinity was also marginally higher at this amount of filler. Thermal behavior of polyethylene nanocomposites (0, 15, 30, and 45) mg was studied by DSC and thermal gravimetric analyzer (TGA). Morphology of the component with 15 mg aluminium nitride is more fibrous as compared to 0 mg aluminium nitride and higher filler loading as shown by SEM images. In order to understand combustibility behavior, tests were performed on microcalorimeter. Its results showed decrease in combustibility in polyethylene nanocomposites as the filler loading increases.

1. Introduction

In the world of thermoplastic, polyolefins find wide range of application because of its unique properties such as low cost, light weight, high strength, durability, noncorrosive nature, and ease in processability. Among the polyolefins, polyethylene is widely used for variety of applications.

In earlier studies, polyethylene (PE) was synthesized using metallocene catalysts [1]. Wherein methyl aluminoxane (MAO) was used as the cocatalyst [2]. In regard to catalytic activity in polymerization of ethylene, metallocene catalysts provided more flexibility than Ziegler-Natta catalysts, and are also in use for many industrial purposes [3–8].

Several studies have been made to improve the various properties of polyethylene by the addition of organic and inorganic fillers [9–13]. Among these fillers, inorganic fillers increase the thermal properties of the polyethylene significantly [14–18]. In the last two decades, among various

inorganic fillers, aluminium nitride (AlN) is of special interest due to its unique thermal properties [19]. Earlier Yu et al. [20] studied the thermal conductivity and thermal stability of the nano-AlN-filled cycloaliphatic epoxy/trimethacrylate. The effect of microsized ($\leq 10 \mu\text{m}$) AlN on the properties of polyether ether ketone (PEEK) prepared by solution blending was studied by Boey et al. [21] who reported that AlN can act as a good nucleating agent in the crystallinity of the polymer. Incorporation of AlN having ($\leq 10 \mu\text{m}$) in polystyrene also increased the thermal conductivity and high thermal conductivity was obtained for the composites having 20 wt.% filler [22].

The present work reports studies on the thermal properties of polyethylene nanocomposites prepared by using metallocene catalysts in the presence of AlN. Organic polymers are combustible, and flame retardants are used to suppress the combustible process [23, 24]. Since AlN provided better thermal behaviour within the polymer matrix, therefore in

the present paper, effect on combustible behaviour was also noted with the help of microcalorimeter.

2. Experimental

2.1. Materials. AlN having size less than 100 nm, zirconocene (catalyst), Toluene, and cocatalyst MAO were purchased from Aldrich Chemicals and kept in oxygen-free environment to avoid any contamination.

2.2. Ethylene Polymerization. Polymerization of ethylene was performed in a 250 mL round-bottom flask equipped with a magnetic stirrer. The zirconocene catalyst (6 mg) and required amount of nano-AlN (15, 30, and 45) mg were added to the flask. The reactor was charged with toluene coming from solvent purification system so that any of the contaminations might not affect the catalysts and cocatalyst. MAO was used as a cocatalyst and as scavenger. Catalyst, cocatalyst, and solvent placement within the reactor were done inside a glove box. Then reactor was taken out from glove box and immersed in a constant temperature bath previously set to a desired temperature. After ensuring that bath temperature and reactor temperature were the same, ethylene was introduced into the reactor through an external chamber after evacuating nitrogen gas using vacuum. Polymerization was quenched after 30 minutes by adding methanol. The contact time between AlN and catalytic system prior to polymerization was 3 minutes. The polymer was washed with an excess amount of methanol and dried in an oven at 50°C. The conditions used for the study are given in Table 1.

2.2.1. Activity. Activity of the catalysts is measured by weighing the product and was noted as ratio of amount of product (polyethylene nanocomposite) to amount of catalyst consumed.

3. Characterization

3.1. Differential Scanning Calorimeter (DSC). The melting and crystallization behavior of the composites were determined by using DSC-Q1000, TA instruments. To overcome the thermal history, heating and cooling was done for both first and second cycles under nitrogen atmosphere at the rate of 10°C/min and 5°C/min, respectively, from a temperature of -10°C to 200°C, and third cycle was performed at a rate of 10°C/min under nitrogen atmosphere and is analyzed in this study.

3.2. Wide-Angle X-Ray Diffraction (WAXD). Measurements were obtained through Shimadzu X-ray diffractometer (40 kV, 40 mA) using Ni-filtered Cu K α radiation from 10 to 80 (in 2 θ) with 15 s standing per step, and crystallinity was determined [25].

3.3. Thermal Gravimetric Analysis (TGA). Thermal degradation studies were performed by thermogravimetric measurements using SDT Q600 (TA instruments). Samples weighing

TABLE 1: Experimental conditions used for the preparation of polyethylene through insitu polymerization by using zirconocene and MAO co-catalyst system.

Entry no.	Filler (mg) ^a	Temp (°C)	Activity ^d
1	0 ^c	30	149.46
2	15	30	329.62
3	30	30	189.41
4	45	30	107.01
5	0 ^c	60	181.15
6	15	60	235.54
7	0 ^{b,c}	30	132.80
8	15 ^b	30	267.67

^a AlN.

^b with 3 mL MAO.

^c Control.

^d $\times 10^{-5}$ gPE/mol Zr h bar.

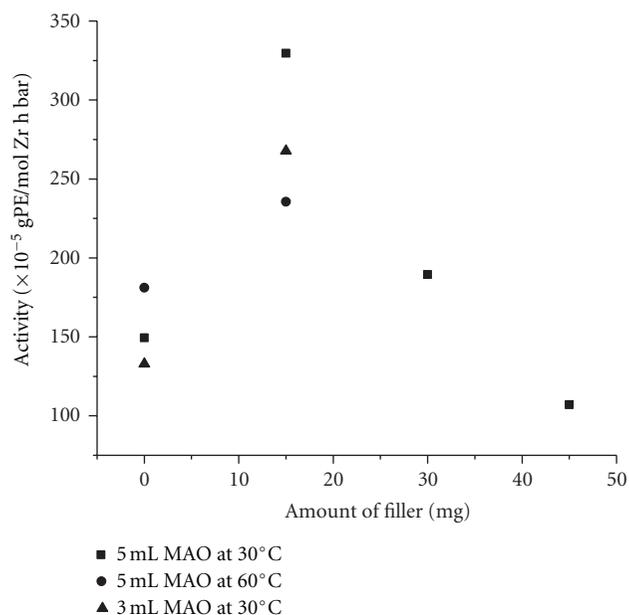


FIGURE 1: Activity of synthesized polyethylene nanocomposites at different experimental conditions.

approximately 5 mg were heated in nitrogen atmosphere from 25° to 650°C at a heating rate of 10°C per minute.

3.4. Scanning Electron Microscopy (SEM). The polymer surface was gold coated, and then surface morphology was studied by using scanning electron microscopy (LYRA3GM, TESCAN).

3.5. Microcalorimeter (MC). Heat release rate (HRR) and ignition temperature were determined using microcalorimeter (FTT Microcalorimeter), and sample size was kept at 3 mg.

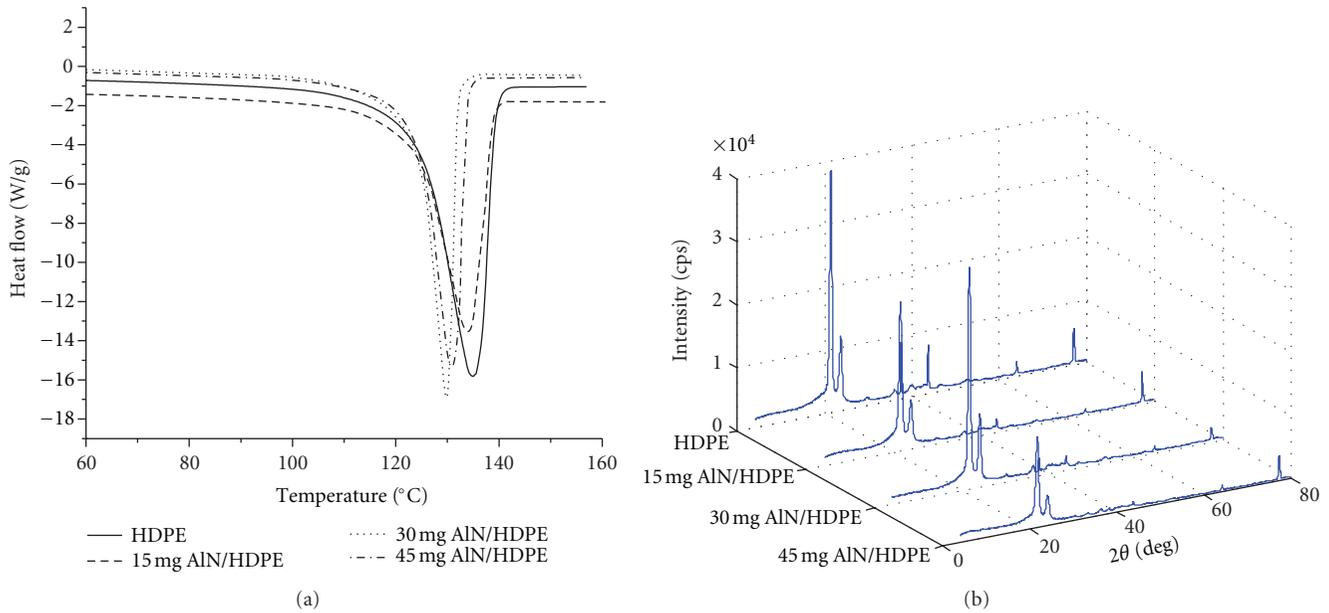


FIGURE 2: (a): DSC heating curves of nano-AlN-filled polyethylene composites. (b): X-ray diffraction (XRD) intensity versus 2-theta (deg).

4. Results and Discussions

4.1. Activity. Figure 1 represents the variation in the activity of synthesized polyethylene under various experimental conditions. It was found that the activity of polymerization reaction was higher for the composites having 15 mg of nanofiller (Table 1, entry no. 2) which were prepared using 5 mL of cocatalyst at 30°C. However, further increase in filler content does not improve the activity of polymerization compared to the control (Table 1, entry no. 3 and 4). This observation is similar to that observed earlier in case of Mn-doped-titania on the activity of metallocene catalyst by *in situ* ethylene polymerization [25]. In order to verify the influence of temperature on activity, reaction was conducted at 60°C (Table 1, entry no. 5 and 6). It is clear that at high temperature (60°C) activity of reaction increased (entry no. 6) when compared to its control (entry no. 5). However at 60°C, activity of the catalysts is less than the activity obtained for the reaction at 30°C (Table 1). Reduction in the amount of cocatalyst also increased the activity of the reaction with an incorporation of the same amount of filler (i.e., 15 mg, entry no. 8) as compared to its control (entry no. 7).

4.2. Differential Scanning Calorimeter (DSC) and Wide-Angle X-Ray Diffraction (WAXD). Figure 2(a) displays the DSC thermograms (heating curve) of polyethylene composites as a function of the amount of AlN. The ΔH_{fus} (heat of fusion) and T_m (melting temperature) values along with the percentage of crystallinity for the blends as a function of AlN content are summarized in Table 2. It can be seen that as the amount of nano-AlN increases, T_m value shifts slightly towards the lower temperature. This can be attributed to the reduction in the lamellar thickness of crystallites imparted by the presence of AlN in the matrix as observed earlier in case

of AlN-reinforced HDPE composites [26]. The percentage of crystallinity was calculated using the following expression as shown in Table 2:

$$\% \text{ of crystallinity} = \left(\frac{\Delta H_{\text{fus}}}{\Delta H_{\text{fus}}^0} \right) \times 100, \quad (1)$$

where ΔH_{fus} is the enthalpy of fusion of the polyethylene composites, and ΔH_{fus}^0 is the enthalpy of fusion of the 100% crystalline polyethylene. ΔH_{fus}^0 of polyethylene was taken as 293 J/g [27]. Incorporation of 15 mg of AlN increased the percentage of crystallinity of the polyethylene, and at higher filler loading, it shows a decreasing trend. This increase is attributed to the heterogeneous nature imparted by the nanofiller, which results in an increase in the crystallinity of the composites [28, 29]. An increase in the crystal nucleation in the region surrounding the reinforced particles also attributes to increase in the crystallinity of the composites [30, 31]. However, at higher filler loading, agglomeration of the nanofiller may occur and a reduction in the mobility of the polymer chains with consequent decrease in the crystallite size and hence a reduction on the percentage of crystallinity [31–33].

Higher melting temperature in HDPE/15 mg AlN nano-composite can be supported by the results of GPC (gel permeation chromatography). Molecular weight (M_w) of HDPE/15 mg AlN is higher as compared to HDPE (control) and higher filler loadings of polyethylene AlN nanocomposites (Table 1).

Crystallinity is determined through wide-angle X-ray diffraction (WAXD), and it showed the same trend as from DSC results as shown by Figure 2(b). Conventional method is used for measuring the percentage of crystallinity [34]. The imperfection of crystals in the presence of the AlN in homogeneities can also contribute to the decrease in

TABLE 2: DSC, XRD and GPC results of AlN filled polyethylene composites.

Material	ΔH_{fus} (J/g)	T_m ($^{\circ}\text{C}$)	Percentage crystallinity (DSC)	Percentage crystallinity (XRD)	M_w	PDI
HDPE	207	135	70	66	209,693	10.132
15 AlN/HDPE	216	133	74	68	213,068	3.538
30 AlN/HDPE	210	130	71	66	48,983	6.468
45 AlN/HDPE	201	131	68	65	64,245	31.10

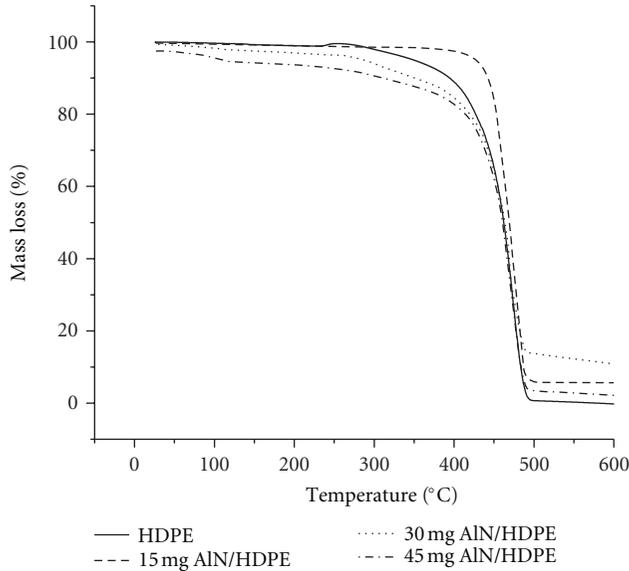


FIGURE 3: TG plots of nano-AlN-filled polyethylene composites.

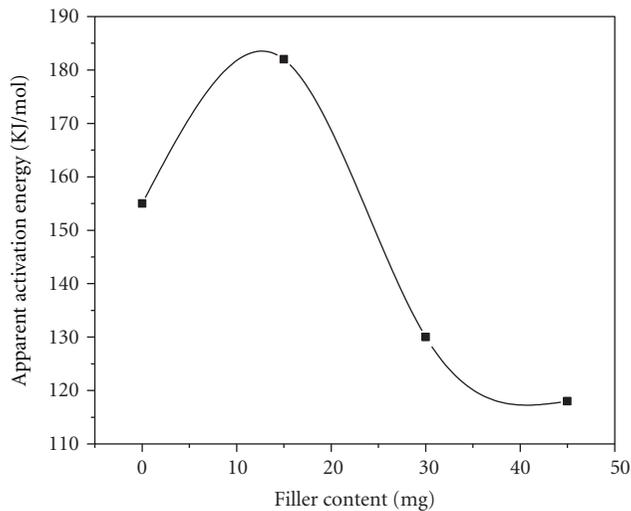


FIGURE 4: Change in activation energy for the AlN/polyethylene composites.

crystallinity [35]. This observation has been corroborated with the results of TGA analysis.

4.3. Thermal Gravimetric Analysis (TGA). Figure 3 displays the thermogravimetric (TG) curves for PE-AlN nanocomposites as a function of the amount of filler. From the

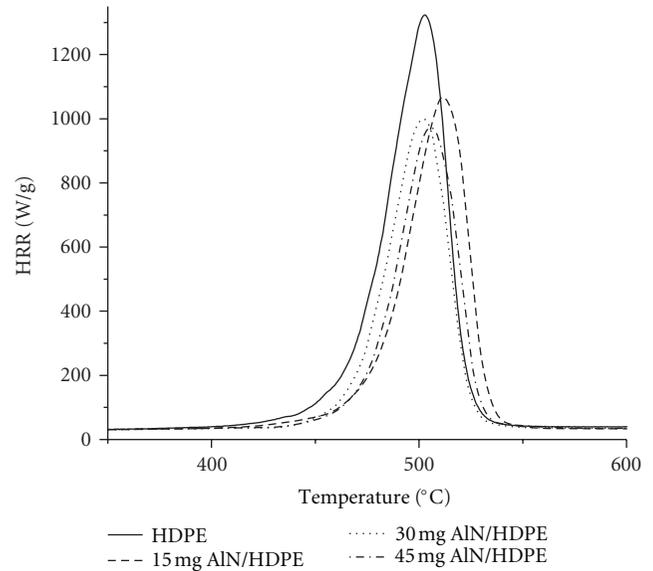


FIGURE 5: Microcalorimeter curves (heat release rate and temperature) of polyethylene AlN nanocomposites.

TG curves, it is clear that degradation kinetics starts at a temperature of 300 $^{\circ}\text{C}$, and maximum degradation occurred in the range of 425 to 450 $^{\circ}\text{C}$, and there is no significant effect in the maximum degradation temperature of the composites. From Figure 3, it is also clear that addition of 15 mg of AlN in the polyethylene matrix increases the thermal stability of the composites however decreases at higher filler loading. This can be explained as follows: in the case of composites having 15 mg of AlN, due to its good dispersion in the polymer matrix, dissipation of heat between filler and the matrix occurs efficiently, thereby there is an increase in the thermal stability of the composites. Also the low heat capacity of AlN (0.738 J/g/ $^{\circ}\text{C}$) compared to HDPE (1.82009 J/g/ $^{\circ}\text{C}$) causes to absorb heat rapidly which results in the degradation of polyethylene at higher temperature [36]. Even though, at higher filler concentration, interparticle distance between fillers decreases, thereby agglomeration and reduction in interfacial area between AlN and PE matrix occurs, and this results in the lowering of the thermal stability of the composites. The same trend has been observed by Goyal et al. in the AlN-reinforced PEEK composites [37]. The degradation kinetics of the composites is calculated by using the Broidto method [38] with an assumption that the

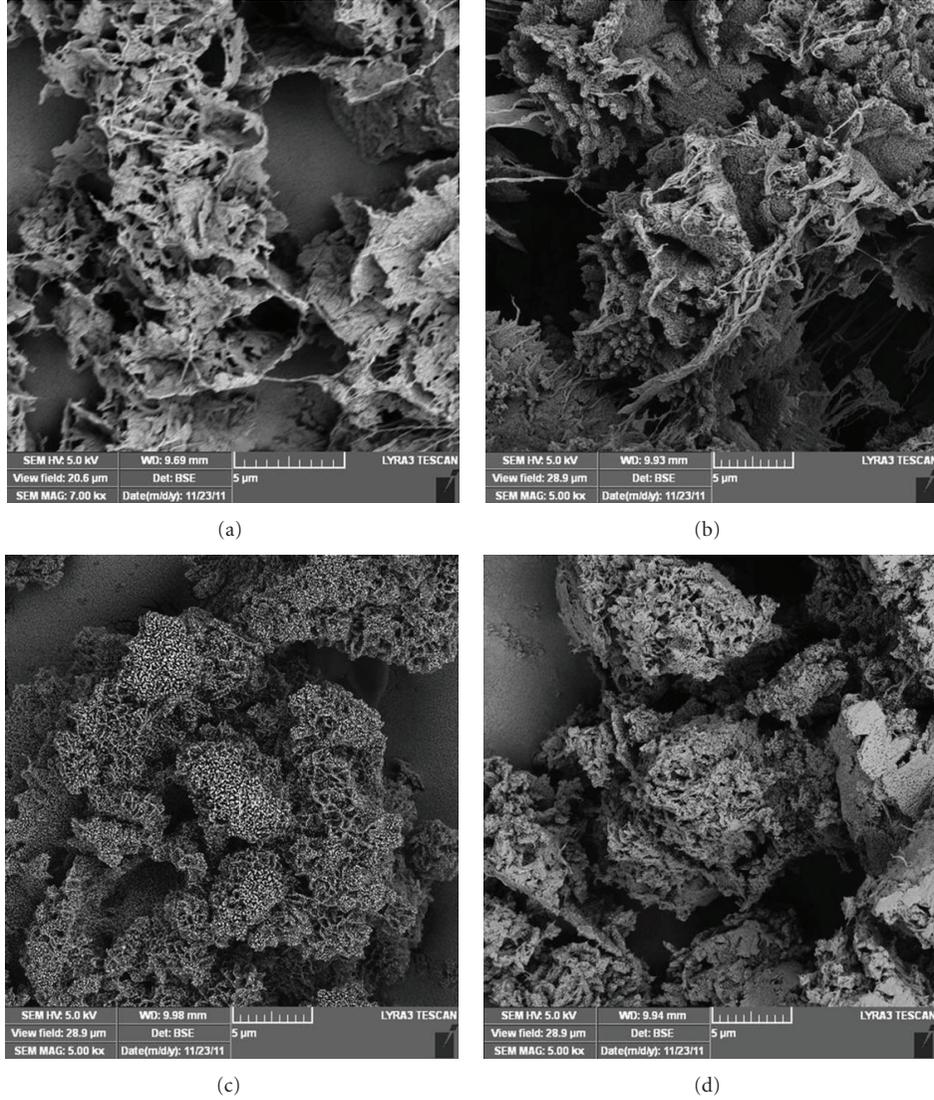


FIGURE 6: Scanning electron microscopy of nano-AlN-filled polyethylene composites. (a) HDPE (control), (b) 15 mg AlN/HDPE, (c) 30 mg AlN/HDPE, and (d) 45 mg AlN/HDPE.

degradation follows a first-order reaction or a superposition of first-order process. This assumption of Broido leads to:

$$\ln[-\ln(1-\alpha)] = \ln K - \frac{\Delta E}{RT}, \quad (2)$$

where α is the amount of polymer degraded at time t , ΔE is the change in activation energy, R is the universal gas constant, K is apparent activation energy, and T is the temperature in Kelvin scale. In this, α can be calculated using the following equation:

$$\alpha = \frac{W_0 - W_t}{W_0 - W_\infty}, \quad (3)$$

where W_t is the mass at time t , W_0 is the initial mass, and W_∞ is the mass after infinite time. The advantage of Broido's method of calculating the activation energy of thermal

stability is that the result does not depend upon the value of heating rate and is independent of the value of temperature at which the reaction is maximum. The results obtained by using Broido's method for the PE-AlN nanocomposites are given in Figure 4. It can be seen that composites having 15 mg of AlN show maximum activation energy as compared to other compositions because of high degradation temperature.

4.4. Microcalorimeter (MC). Combustibility test data as obtained through Microcalorimeter in terms of heat release rate and decomposition temperature are shown in Figure 5 and Table 3. Fire test data obtained through it can be correlated to the results obtained through Cone Calorimeter [39]. It is apparent that with increase in the content of filler,

TABLE 3: Micro-calorimeter results showing decomposition temperature (°C) and heat release rate (W/g).

Material	Decomposition temperature (°C)	HRR (W/g)
PE	502.7	1323.2
PE/15 mg AlN	511.8	1067.4
PE/30 mg AlN	501.8	998.7
PE/45 mg AlN	505.6	972.6

heat release rate decreases indicating an increase in thermal stability and decrease in combustibility [23, 24].

4.5. *Scanning Electron Microscopy (SEM)*. Figures 6(a)–6(d) show surface morphology; HDPE appears to be less fibrous (see Figure 6(a)) than HDPE/15 mg AlN (see Figure 6(b)). Here, fibrous chains are formed making the material more crystalline. In the case of PE/30 mg AlN (see Figure 6(c)), it appears that excess amount of AlN-nano particles restricted the growth of chains, and the structure is less fibrous. In PE/45 mg, AlN fibrous surfaces became least prominent (see Figure 6(d)). The same type of fibrous morphology was also observed in another study where AlN nanoparticles were used [40]. Scanning electron microscopy (SEM) provided us with an advantage of exploring the surface morphology of PE (pure) and PE/AlN composites in a better way, and the same type of effect is also observed in previous studies [41].

5. Conclusion

Ethylene polymerization was done to form polyethylene nanocomposites with nanoaluminum nitride. Catalyst activity was higher at 15 mg nanoaluminum nitride. Differential scanning calorimeter (DSC) results show that melting temperature is minutely affected by an increase in amount of filler. Whereas Percentage crystallinity data from differential scanning calorimeter (DSC) and X-ray diffraction (XRD) shows that at 15 mg AlN/percentage crystallinity increased marginally. It is also apparent from Micro calorimeter (MC) data that with increase in the content of filler, heat release rate decreases, indicating a decrease in combustibility. Surface morphology was observed through scanning electron microscopy (SEM); at 15 mg AlN/HDPE fibrous chains were formed, whereas at 30 mg AlN/HDPE and 45 mg AlN/HDPE, it became less prominent.

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References

- [1] S. C. Moreira and M. D. F. V. Marques, "Polyethylene synthesis using zeolite as support for metallocene catalyst," *European Polymer Journal*, vol. 37, no. 10, pp. 2123–2130, 2001.
- [2] F. López-Linares, A. D. Barrios, H. Ortega, A. Karam, G. Agrifoglio, and E. González, "Modification of polyethylene polydispersity by blending a ziegler-natta catalyst with a group of IV-half metallocene or scorpionate complexes," *Journal of Molecular Catalysis A*, vol. 179, no. 1-2, pp. 87–92, 2002.
- [3] M. Jezequel, V. Dufaud, M. J. Ruiz-García et al., "Supported metallocene catalysts by surface organometallic chemistry. Synthesis, characterization, and reactivity in ethylene polymerization of oxide-supported mono- and biscyclopentadienyl zirconium alkyl complexes: establishment of structure/reactivity relationships," *Journal of the American Chemical Society*, vol. 123, no. 15, pp. 3520–3540, 2001.
- [4] R. Van Grieken, A. Carrero, I. Suarez, and B. Paredes, "Ethylene polymerization over supported MAO/(nBuCp)₂ZrCl₂ catalysts: influence of support properties," *European Polymer Journal*, vol. 43, no. 4, pp. 1267–1277, 2007.
- [5] C. Covarrubias and R. Quijada, "High catalytic activity of SBA-15-supported metallocene toward ethylene polymerization: the effect of the ordered porous structure of the support," *Catalysis Communications*, vol. 10, no. 6, pp. 995–1001, 2009.
- [6] P. A. Zapata, R. Quijada, I. Lieberwirth, and H. Palza, "Synthetic layered and tube-like silica nanoparticles as novel supports for metallocene catalysts in ethylene polymerization," *Applied Catalysis A*, vol. 407, no. 1-2, pp. 181–187, 2011.
- [7] K.-J. Chu, C. Li Pi Shan, J. B. P. Soares, and A. Penlidis, "Copolymerization of ethylene and 1-hexene with in-situ supported Et[Ind]₂ZrCl₂," *Macromolecular Chemistry and Physics*, vol. 200, no. 10, pp. 2372–2376, 1999.
- [8] W. Owpradit and B. Jongsomjit, "A comparative study on synthesis of LLDPE/TiO₂ nanocomposites using different TiO₂ by in situ polymerization with zirconocene/dMMAO catalyst," *Materials Chemistry and Physics*, vol. 112, no. 3, pp. 954–961, 2008.
- [9] T. S. Halbach and R. Mülhaupt, "Boehmite-based polyethylene nanocomposites prepared by in-situ polymerization," *Polymer*, vol. 49, no. 4, pp. 867–876, 2008.
- [10] M. C. Kuo, C. M. Tsai, J. C. Huang, and M. Chen, "PEEK composites reinforced by nano-sized SiO₂ and Al₂O₃Os particulates," *Materials Chemistry and Physics*, vol. 90, no. 1, pp. 185–195, 2005.
- [11] C. Desharun, B. Jongsomjit, and P. Prasertdam, "Study of LLDPE/alumina nanocomposites synthesized by in situ polymerization with zirconocene/d-MMAO catalyst," *Catalysis Communications*, vol. 9, no. 4, pp. 522–528, 2008.
- [12] B. Jongsomjit, J. Panpranot, M. Okada, T. Shiono, and P. Prasertdam, "Characteristics of LLDPE/ZrO₂ nanocomposite synthesized by in-situ polymerization using a zirconocene/MAO catalyst," *Iranian Polymer Journal*, vol. 15, no. 5, pp. 433–439, 2006.
- [13] I. Krupa, I. Novák, and I. Chodák, "Electrically and thermally conductive polyethylene/graphite composites and their mechanical properties," *Synthetic Metals*, vol. 145, no. 2-3, pp. 245–252, 2004.
- [14] R. K. Gupta and E. Kennel, *Polymer Nano-composite Handbook*, CRC Press, Boca Raton, Fla, USA, 2010.
- [15] H. Ishida and S. Rimdusit, "Very high thermal conductivity obtained by boron nitride-filled polybenzoxazine," *Thermochimica Acta*, vol. 320, no. 1-2, pp. 177–186, 1998.

- [16] M. Philipp, P. C. Gervais, R. Sanctuary et al., "Effect of mixing sequence on the curing of amine-hardened epoxy/alumina nanocomposites as assessed by optical refractometry," *Express Polymer Letters*, vol. 2, no. 8, pp. 546–552, 2008.
- [17] E. Kamseu, B. Nait-Ali, M. C. Bignozzi, C. Leonelli, S. Rossignol, and D. S. Smith, "Bulk composition and microstructure dependence of effective thermal conductivity of porous inorganic polymer cements," *Journal of the European Ceramic Society*, vol. 32, no. 8, pp. 1593–1603, 2012.
- [18] A. S. Luyt, J. A. Molefi, and H. Krump, "Thermal, mechanical and electrical properties of copper powder filled low-density and linear low-density polyethylene composites," *Polymer Degradation and Stability*, vol. 91, no. 7, pp. 1629–1636, 2006.
- [19] Y. Xu, D. D. L. Chung, and C. Mroz, "Thermally conducting aluminum nitride polymer-matrix composites," *Composites A*, vol. 32, no. 12, pp. 1749–1757, 2001.
- [20] J. H. Yu, J. K. Duan, W. Y. Peng, L. C. Wang, P. Peng, and P. K. Jiang, "Influence of nano-ALN particles on thermal conductivity, thermal stability and cure behavior of cycloaliphatic epoxy/trimethacrylate system," *Express Polymer Letters*, vol. 5, no. 2, pp. 132–141, 2011.
- [21] F. Y. C. Boey, X. L. Song, C. Y. Yue, and Q. Zhao, "Effect of AlN fillers on the properties of a modified bismaleimide resin," *Journal of Materials Processing Technology*, vol. 89–90, pp. 437–439, 1999.
- [22] S. Yu, P. Hing, and X. Hu, "Thermal conductivity of polystyrene-aluminum nitride composite," *Composites A*, vol. 33, no. 2, pp. 289–292, 2002.
- [23] G. Pal and H. Mackasy, *Plastics Their Behaviour in Fires*, Acta Polymerica, Akademie Verlag GmbH, Berlin, Germany, 1991.
- [24] J. Troitzsch, *International Plastics Flammability Handbook*, Hanser, 2nd edition, 1990.
- [25] S. H. A. Kaleel, B. K. Bahuleyan, S. K. De, M. J. Khan, R. Sougrat, and M.A. Al-Harathi, "Effect of Mn doped-titania on the activity of metallocene catalyst by in situ ethylene polymerization," *Journal of Industrial and Engineering Chemistry*, vol. 18, no. 5, pp. 1836–1840, 2012.
- [26] A. R. Horrocks and K. Price, *Fire Retardant Materials*, CRC Press, Boston, Mass, USA, 2001.
- [27] J. E. Mark, *Physical Properties of Polymers, Handbook AIP*, Woodbury, 1996.
- [28] W. Zhou, "Thermal and dielectric properties of the AlN particles reinforced linear low-density polyethylene composites," *Thermochimica Acta*, vol. 512, no. 1-2, pp. 183–188, 2011.
- [29] D. M. Hoffman and B. M. McKinley, "Crystallinity as a selection criterion for engineering properties of high density polyethylene," *Polymer Engineering and Science*, vol. 25, no. 9, pp. 562–569, 1985.
- [30] B. K. Bahuleyan, S. De Kumar, P. U. Sarath et al., "Effect of aluminium nitride on the properties of polyethylene obtained by In situ polymerization using Ni(II) diimine complex," *Macromolecular Research*, vol. 20, no. 7, pp. 772–775, 2012.
- [31] J. Gu, Q. Zhang, J. Dang, J. Zhang, and Z. Yang, "Thermal conductivity and mechanical properties of aluminum nitride filled linear low-density polyethylene composites," *Polymer Engineering and Science*, vol. 49, no. 5, pp. 1030–1034, 2009.
- [32] A. Dasari, J. Rohrmann, and R. D. K. Misra, "On the scratch deformation of micrometric wollastonite reinforced polypropylene composites," *Materials Science and Engineering A*, vol. 364, no. 1-2, pp. 357–369, 2004.
- [33] S. H. A. Kaleel, B. K. Bahuleyan, M. J. Khan, and M. A. Al-Harathi, "Thermal and mechanical properties of polyethylene/doped-TiO₂ nanocomposites synthesized using in situ polymerization," *Journal of Nanomaterials*, vol. 2011, Article ID 964353, 6 pages, 2011.
- [34] K. W. Garrett and H. M. Rosenberg, "The thermal conductivity of epoxy-resin / powder composite materials," *Journal of Physics D*, vol. 7, no. 9, article 311, pp. 1247–1258, 1974.
- [35] G. E. Youngblood, D. J. Senior, R. H. Jones, and S. Graham, "The transverse thermal conductivity of 2D-SiC_f/SiC composites," *Composites Science and Technology*, vol. 62, no. 9, pp. 1127–1139, 2002.
- [36] A. Sami, E. David, and M. Frechette, "Dielectric response of high density polyethylene/SiO₂ composites," in *Proceedings of the Annual Report Conference on Electrical Insulation and Dielectric Phenomena (CEIDP'10)*, pp. 1–4, October 2010.
- [37] R. K. Goyal, Y. S. Negi, and A. N. Tiwari, "Preparation of high performance composites based on aluminum nitride/poly(ether-ether-ketone) and their properties," *European Polymer Journal*, vol. 41, no. 9, pp. 2034–2044, 2005.
- [38] A. Broido, "A simple, sensitive graphical method of treating thermogravimetric analysis data," *Journal of Polymer Science A-2*, vol. 7, no. 10, pp. 1761–1773, 1969.
- [39] F. Laoutid, L. Bonnaud, M. Alexandre, J. M. Lopez-Cuesta, and P. Dubois, "New prospects in flame retardant polymer materials: from fundamentals to nanocomposites," *Materials Science and Engineering R*, vol. 63, no. 3, pp. 100–125, 2009.
- [40] B. K. Bahuleyan, M. A. Atieh, S. K. De, M. J. Khan, and M. A. Al-Harathi, "Easy one-pot method to control the morphology of polyethylene/carbon nanotube nanocomposites using metallocene catalysts," *Journal of Polymer Research*, vol. 19, no. 2, Article ID 9744, 2012.
- [41] R. Brambilla, C. Radtke, F. C. Stedile, J. H. Z. Dos Santos, and M. S. L. Miranda, "Metallocene catalyst supported on silica-magnesia xerogels for ethylene polymerization," *Applied Catalysis A*, vol. 382, no. 1, pp. 106–114, 2010.



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