Research Article

Studies on Mechanical, Thermal, and Morphological Properties of Glass Fibre Reinforced Polyoxymethylene Nanocomposite

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Polyoxymethylene is a material which has excellent mechanical properties similar to Nylon-6 filled with 30% GF. 75% POM and 25% glass fibre (POMGF) were blended with nanoclay to increase the tensile and flexural properties. Samples were extruded in twin screw extruder to blend POMGF and (1%, 3%, and 5%) Cloisite 25A nanoclay and specimens were prepared by injection moulding process. The tensile properties, flexural properties, impact strength, and hardness were investigated for the nanocomposites. The fibre pull-outs, fibre matrix adhesion, and cracks in composites were investigated by using scanning electron microscopy. 1% POMGF nanocomposite has low water absorption property. Addition of nanoclay improves the mechanical properties and thermal properties marginally. Improper blending of glass fibre and nanoclay gives low tensile strength and impact strength. SEM image shows the mixing of glass fibre and nanoclay among which 1% POMGF nanocomposite shows better properties compared to others. The thermal stability decreased marginally only with the addition of nanoclay.

1. Introduction

Polyoxymethylene is an engineering thermoplastic used in precision parts requiring high stiffness, low friction, and excellent dimensional stability. As any other synthetic polymers, it is produced by different chemical firms with slightly different formulas and sold variously by such names as *Delrin*, *Celcon*, *Duracon*, and *Hostaform*. Typical applications for injection-molded POM include high performance engineering components such as small gear wheels, ball bearings, ski bindings, fasteners, knife handles, lock systems, and model rocket launch buttons. Polyoxymethylene (POM) is also known as acetal, polyacetal, and polyformaldehyde. It was introduced to industrial applications in 1956 as a potential replacement for die-cast metals and is widely used in automotive applications, electrical applications, electronics, and many industrial fields [1]. This is due to its outstanding and well-balanced properties and because no other products can be substituted for POM in some application fields. POM

occupies an important position in industry as well as in society. It shows excellent physical and mechanical properties which are mainly based on its high crystallinity. It is expected that the development of high-value-added materials will result in the requirement to distinguish them from existing POM materials [2, 3]. POM, however, has a poor impact resistance, which limits its range of applications. POM polymer also suffers from limited processing temperature and low heat deflection temperature. Polyoxymethylene (POM), with $[-CH_2-O-]$ as the main chain, is an engineering plastic with high mechanical strength, excellent abrasion resistance, fatigue resistance, and moldability. It can replace some metals and nonmetals to be used in many areas, for example, in electrical and electronic applications, automotive applications, and precision machine applications [4, 5]. Nevertheless, up to now, lots of efforts have been devoted to further improvement of the mechanical strength of POM by means of incorporation with fillers such as calcium carbonate, talc, diatomite, clay, and glass fibres. Several authors reported that

due to addition of glass fibre the heat deflection temperature of POM was found to increase about 20–40°C [6–8]. Addition of glass fibre with POM increases the mechanical and thermal properties with 25% ratio. PPcp-POM (Delrin, Homopolymer) (5, 10, and 20 wt%) was blended using a twin screw extruder and was tested. The impact (5% POM) and flexural modulus (20% POM) were found to be higher than those of PPcp itself. When SGF (short glass fibre) (20 wt%) was used, there is further improvement in the flexural modulus, which is generally more useful for design purposes. However, for optimum mechanical and thermal properties with better impact strength, the PP copolymer should be present at more than about 40% in the blend. Addition of nanocomposite enhanced thermal and water resistance and marginal reduction in transparency [9–11]. Cloisite 25A blended with rPET increases the tensile strength by 5%. Nanoclay increases the flexural strength with rubber material [12].

POM composites composed of abacus and cellulose fibres were studied in which the tensile strength of abacus fibre was improved by the addition of natural fibre without increasing its density [13]. Toughened and reinforced POM/MWCNT composites were prepared by compounding POM with MWCNTs at low filler content. The mechanical strength and toughness of the composites were enhanced at 1 wt% MWCNT loading. The storage and loss modulus of the composites both increased at all temperatures by introducing rigid MWCNTs, indicating an improved stiffness of composites and strong entanglement between POM and MWCNTs [14]. The studies on the morphology and properties of melt-blended poly(acrylonitrile-butadiene-styrene) (ABS) toughened polyoxymethylene (POM)/clay nanocomposites at different clay loadings (2.5 and 5 phr) revealed that the number average domain diameter (D_n) of the ABS droplets in the (75/25 w/w) POM/ABS blend gradually decreased with increase in clay loading [15].

The field of clay-based polymer nanocomposites has attracted many researchers for the last three decades for their tremendous improvement in properties resulting from the long range interactions between polymer and surface of the clay. Blending different polymers has been a very convenient and attractive method for the production of materials with specific end-use applications. However, general immiscibility of the polymers associated with inherent thermodynamic incompatibility results in the formation of immiscible polymer blends in most of the cases and, thus, leads to the formation of phase separated blend with matrix-droplet morphology, in which the major constituent forms the matrix phase and the minor component acts as the dispersed phase [16]. Thus, attainment of better properties in immiscible polymer blends demands improvement in miscibility. Addition of block or graft copolymers as compatibilizer during processing helps in reducing interfacial tension and increasing interfacial adhesion through bridging or making entanglement between the polymers that improves the compatibility of the blends [17–21]. Many research groups [22–30] have reported nanoclay as a good compatibilizer in immiscible polymer blends over the past several years.

Polyoxymethylene (POM) is an engineering thermoplastic used in precision parts that require high stiffness, low friction, excellent dimensional stability, high heat resistance, and good dielectric property. Because of its 70% crystallinity level and formation of spherulites (spherical semicrystalline regions) [31] POM exhibits excellent mechanical and technological properties including tensile strength and flexural modulus. Furthermore, POM possesses high creep, fatigue, and corrosion resistance which lead it to a number of commercial applications, for example, car indoor structural parts with long-term thermal stability and resistance against UV-irradiation, bearings, phones (dialing parts), pump impellers, home electronics and hardware, pneumatic components, and many other applications.

In this work, POM was mixed with the glass fibre and Cloisite 25A and reinforced and toughened POMGF nanocomposites were prepared. The effect of glass fibre and nanoclay addition on the mechanical properties and crystallization behaviour and the reinforcing mechanism of POM were investigated. The composites presented wide applications as construction material, such as fixtures, pump and fan propellers, gears, bearing liners, and rings.

2. Experimental

2.1. Materials. The POM used in this work is a commercial grade without any additives supplied by DuPont, USA, in the form of pellets with melt flow index 10 g/10 min and a density of 910 kg/m³. Cloisite 25A (a montmorillonite modified with methyl) was supplied by Southern Clay Products, Inc., USA. Hereafter Cloisite 25A is referred to as nanoclay. Chopped E-GF (glass fibre) surface was treated with silane and having a density of 2550 kg/m³, average diameter of 14 µm, and length of 6 mm, obtained from KCC Corporation, Korea, and was used as the principle reinforcement.

2.2. Composites Preparation. Compositions were physically premixed and then compounded using the Brabender, KETSE 20/40 (Germany) twin screw extruder. The materials extruded from both formulations were pelletized into length of about 6 mm. In order to produce POM/GF/NC composites, the different ratios of the POM/NC and GF were physically mixed and recompounded in a twin screw extruder, using the same temperature profile and screw speed of 100 rpm. The dumbbell-shaped tensile and impact tests specimens, according to ASTM standard D63814 and ASTM standard E 23, respectively, were then injection-moulded using a Boy 55 M (Germany), with a 55-ton clamping force injection moulding machine. The processing temperature was set between 175°C and 185°C and the mould temperature was set at 25°C. The screw speed was maintained at 30–50 rpm.

2.3. Characterisation

2.3.1. Mechanical Analysis. Tensile and flexural tests were performed at a test speed of 2 mm/min according to EN ISO 527 and EN ISO 178 using a Zwick UPM 1446 machine. All

tests were performed at room temperature (23°C) and at a relative humidity of 50%. Instrumented notched Charpy impact test was carried out using 10 notched samples according to EN ISO 179 using Zwick Charpy impact machine. Impact tests were carried out using a low velocity falling weight impact tester at room temperature in penetration mode according to EN ISO 6603-2. The impactor's mass was 3.65 kg and the impact velocity was 4.4 m/s.

2.3.2. Hardness. Hardness is tested by Rockwell hardness apparatus and Shore D.

2.3.3. Water Absorption. Water absorption test for POM nanocomposites was performed as per ASTM D570. The specimens were immersed in distilled water at room temperature for 24 hours. The percentage increase in weight of the specimen after the immersion was calculated by the following formula:

$$\text{Water Absorption (\%)} = \left[\frac{W - W_0}{W_0} \right] \times 100, \quad (1)$$

where W is wet weight and W_0 is dried weight.

Cloisite 25A has good mechanical properties and low water absorption.

2.3.4. Thermogravimetric Analysis. The thermogravimetric analysis was done under nitrogen atmosphere in Perkin Elmer instrument, Pyris 7 software at scanning rate of about 10 to 200°C/min.

2.3.5. DSC. DSC experiments were performed with a Perkin Elmer Diamond DSC (USA). Each sample was subjected to heating and cooling cycles at a scanning rate of 10°C/min under nitrogen atmosphere with the nitrogen flow rate of 20 mL/min, in order to prevent oxidation. The test sample of between 5 and 10 mg was crimped in an aluminum pan and tested over a temperature range of 0°C–190°C.

2.3.6. XRD. X-ray diffraction (XRD) patterns of clay-polymer mixtures and the resulting coatings were studied using analytical (model Philips PW 1840) X-ray diffractometer.

2.3.7. Morphology. The morphology of fibre reinforced POMGF nanocomposites was investigated using the scanning electron microscope (SEM) MV2300, by Cam Scan Electron Optics. Flexural samples were fractured after being submerged in liquid nitrogen and test specimens were prepared sputter-coated with gold.

3. Results and Discussion

3.1. Mechanical Properties

3.1.1. Tensile Strength. The mechanical properties of the POMGF nanocomposites such as tensile strength, flexural strength, and impact strength have been evaluated and presented in Table 1. The tensile modulus of polymer nanoclay

composites depends on modulus of the polymer, modulus of the clay platelets, dispersion of the clay, clay loading, and degree of crystallinity in the polymer matrix.

Addition of nanoclay resulted in the decrease in tensile strength with increase in nanoclay content. The decrease in the tensile properties could be due to the immiscibility of the polymer blends with the nanoclay due to weak interfacial interaction between nanoclay and polymer. These observations suggested that the composition of clay has a strong influence on the structural properties of POMGF nanocomposites.

Considering the composition analysis, 1% nanoclay addition showed better tensile strength compared to other concentration ratios and was found to be the optimum composition.

3.1.2. Flexural Strength. The flexural strength test results of POMGF nanocomposites at different nanoclay compositions are given in Table 1. This shows an increase gradually from 86.57 MPa to 102.10 MPa. Flexural strength of POMGF nanocomposites at different compositions like 1%, 3%, and 5% was compared with POM and POMGF. Among these, the 1% POMGF nanocomposite showed high flexural strength of 102.10 MPa. Table 1 showed that incorporation of clay within POMGF matrix resulted in marginal improvement in the mechanical properties which is primarily due to incompatibility between the matrix polymer and the nanoclay. This increment in tensile strength and flexural strength is primarily attributed to the reinforcing characteristics of dispersed nanolayers with high aspect ratio. It is expected that the macromolecules in contact with the solid silica have different responses from those containing the matrix because of the mechanical displacement resulting from elongation, which is responsible for the increased modulus of the nanocomposites [32]. The increase in flexural strength is attributed to the high stiffness of nanolayers.

3.1.3. Impact Strength. The impact strength results of POMGF composites with and without nanoclay are listed in Table 3. As per the data, it was found that impact strength of POMGF nanocomposites decreased with the nanoclay loading. This may be due to variation in interaction between filler and matrix due to change in nature and chemical composition of filler. As per data it was found in both Charpy and Izod tests that impact strength with addition of nanoclay decreased due to the properties of nanoclay, fibre pull-out, and immiscibility.

3.2. Hardness. Hardness is an important property among mechanical properties. Addition of nanoclay increases the hardness of the materials. 1% POMGF nanocomposite shows increase in hardness of 84. It shows the strong glass fibre filler added in the composition.

3.3. Melt Flow Index (MFI) and Water Absorption Test. In case of MFI, the addition of glass fibre decreases the MFI from 10.58 to 4.54 g/min. The decrease in melt flow is due to the high viscous nature of glass fibre. The decrease of MFI

TABLE 1: Mechanical properties.

Material	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (Charpy test) (Kg/m ²)	Impact strength (Izod test) (Kg/m ²)
POM	60.27	86.57	10.823	7.191
POMGF	70.34	96.37	6.352	4.967
1% POMGF	66.15	102.10	6.303	4.042
3% POMGF	57.83	89.76	4.625	4.082
5% POMGF	55.21	78.74	6.460	3.859

TABLE 2: Hardness, MFI, and water absorption.

Material	Hardness	MFI (g/10 min)	Water absorption (g)
POM	82.25	10.58	0.051
POMGF	83.5	4.54	0.037
1% POMGF	84	9.97	0.02
3% POMGF	75.4	7.23	0.051
5% POMGF	70.8	5.73	0.078

from 10.58 to 5.73 g/10 min is due to the high viscous nature of nanoclay which resists the flow of melt. Table 2 depicts the values in which 1% POMGF nanocomposite has better viscosity compared to other compositions.

From the water absorption values found in Table 2 it has been observed that the 1% POMGF nanocomposite absorbs less water than the virgin POM materials. POMGF nanocomposites absorb less water than that of virgin POM due to the presence of glass fibres along with clay.

3.4. TGA. Thermal stability of polymeric composites was shown to be strongly dependent on the degree of nanoclay concentration. At relatively low concentration of nanoclay, the initial thermal stability increased reaching maximum of 1% and decreased when the nanoclay concentration was more than 1%. Thus optimal thermal stabilization was observed at 1% nanoclay concentration. This may be due to internal thermal stability of the clay layers. The shift towards higher temperature was found to be due to the formation of a high performance carbonaceous silicate char residue on the surface of the insulates, the underlying material, and slow escape of volatile products generated during decomposition. Table 3 shows the TGA thermograms of virgin POM, POMGF, and their nanocomposites. It is observed that decomposition of virgin POM started at a temperature of 323.16°C and that of POMGF at 340.66°C. Decomposition temperature decreases as the percentage of nanoclay increases as shown in Figure 1.

3.5. Differential Scanning Calorimetry. The melting and crystallization behavior of virgin POM, POMGF, and their nanocomposites were investigated using DSC and are listed in Table 4. The melting temperature (T_m), crystallization temperature (T_c), and heat of fusion (ΔH_m) for the POM, POMGF, and the nanocomposites were also determined

FIGURE 1: TGA of virgin POM, POMGF, and POMGF nanocomposites.

from the DSC thermogram shown in Figure 2. The melting temperature of pure POM was found to be 170.6°C. Addition of glass fibre increases melting point slightly.

The degree of crystallinity (X_c) can be determined from the heat of fusion normalized to that of POM according to the following equation:

$$X_c = \left(\frac{\Delta H_m}{\Delta H_m^*} \right) 100, \quad (2)$$

where ΔH_m and ΔH_m^* are the melting heats of fusion of the composites and 100% crystalline POM. Addition of nanoclay results in increase of the degree of crystallinity up to 1% POMGF. This indicates that formulation of nucleation sites in the presence of fibres is not significant. The Addition of nanoclay results in marginal reduction or no appreciable changes in the degree of crystallinity.

3.6. Morphological Properties

3.6.1. X-Ray Diffraction Techniques (XRD). The degree of crystallinity is an important parameter to define chemical and physical properties of polymeric material. The changes

TABLE 3: Thermogravimetric data of composites.

Material	Onset temperature (T_1 °C)	Peak temperature ($T_{\max}$ °C)	Weight loss (%) at peak second temperature
POM	301.73	323.16	99.753
POMGF	305.99	340.66	99.601
1% POMGF	294.46	320.53	100.016
3% POMGF	281.42	318.27	99.462
5% POMGF	276.15	293.75	99.084

TABLE 4: Melting and crystallization behavior.

Sample number	Material	Melting point °C	H_m J/g	H_c J/g	% of crystallinity
1	POM	170.6	102.5	-109.3	3.99
2	POMGF	174	155.2	157	1.03
3	1% POMGF	168.3	80.16	90.8	6.32
4	3% POMGF	165.4	95.53	97.6	1.25
5	5% POMGF	157.1	155.2	157	1.03

FIGURE 2: DSC heating curve.

FIGURE 3: XRD of POM, POMGF, and nanocomposites.

in the interlayer distance of clay can generally be elucidated using XRD. A shift to lower angles in the peak represents the formation of an intercalated structure, whereas the disappearance of the peak signals the potential existence of an exfoliated structure. Figure 3 displays the wide angle X-ray diffraction patterns of all the nanocomposites.

X-ray diffraction patterns of POM, POMGF, and nanocomposites are illustrated in Figure 3. The 1% nanocomposites did not exhibit peak within the experimental range, which indicated exfoliated structure. It also demonstrated superior composite performance as discussed under mechanical and thermal properties. Structure of clay breaks due to pressure

exerted by the intercalated polymer leaving behind exfoliated composition. This leads to the disappearance of the peak in the low angle XRD spectra as in Figure 3.

3.6.2. Scanning Electron Microscopy (SEM). The morphology of prepared composite has been investigated using scanning electron microscopy (SEM). SEM images of fractured surface of impact specimen as shown in Figures 4, 5, and 6 revealed nonuniform mixing of fibre and the nanoclay. Further, it was found that mixing of fibre and nanoclay was not homogenized and more pull-out of fibres was observed in the impact test sample and filler has smooth surface. This shows

FIGURE 4: SEM of 1% POMGF.

FIGURE 5: SEM of 3% POMGF.

FIGURE 6: SEM of 5% POMGF.

the immiscibility of nanoclay with fibre, due to the absence of a compatibilizer.

4. Conclusion

Glass fibre reinforced POM nanocomposites were prepared at various weights of nanoclay. 25% glass fibre and 75%

POM (POMGF) were optimized for blending composition. Mechanical properties slightly decreased on addition of glass fibre due to the immiscibility of nanoclay. Tensile strength of nanocomposites decreases due to the improper blending of glass fibre and nanoclay. Flexural strength increases for 1% POMGF nanocomposite. But it has good hardness and low water absorption properties. The thermal stability decreased marginally with the addition of nanoclay.

Conflict of Interests

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

References

- [1] T. Konaka, K. Nakagawa, and S. Yamakawa, "Mechanical and physical properties of ultraoriented polyoxymethylene produced by microwave heating drawing," *Polymer*, vol. 26, no. 3, pp. 462–468, 1985.
- [2] J. He, L. Zhang, and C. Li, "Effect of perfluoroalkylmethacrylate ester-grafted-linear low-density polyethylene on the tribological property of polyoxymethylene—linear low-density polyethylene composites," *Polymer Engineering & Science*, vol. 51, no. 5, pp. 925–930, 2011.
- [3] D. Braun and S. Ross, "Influence of structural parameters on the dynamic mechanical properties of polyacetals," *Die Angewandte Makromolekulare Chemie*, vol. 228, pp. 185–200, 1995.
- [4] S. Hasegawa, H. Takeshita, F. Yoshii, T. Sasaki, K. Makuuchi, and S. Nishimoto, "Thermal degradation behavior of gamma-irradiated acetyloxy end-capped poly(oxymethylene)," *Polymer*, vol. 41, no. 1, pp. 111–120, 2000.
- [5] H. Hama and K. Tashiro, "Structural changes in non-isothermal crystallization process of melt-cooled polyoxymethylene. [I] Detection of infrared bands characteristic of folded and extended chain crystal morphologies and extraction of a lamellar stacking model," *Polymer*, vol. 44, no. 10, pp. 3107–3116, 2003.
- [6] K. Kawaguchi, K. Mizuguchi, K. Suzuki, H. Sakamoto, and T. Oguni, "Mechanical and physical characteristics of cellulose-fiber-filled polyacetal composites," *Journal of Applied Polymer Science*, vol. 118, no. 4, pp. 1910–1920, 2010.
- [7] G. Zachariev, H.-V. Rudolph, and H. Ivers, "Damage accumulation in glassfiber reinforced polyoximethylene under short-term loading," *Composites Part A: Applied Science and Manufacturing*, vol. 35, no. 10, pp. 1119–1123, 2004.
- [8] K. Kawaguchi, E. Masuda, and Y. Tajima, "Tensile behavior of glass-fiber-filled polyacetal: influence of the functional groups of polymer matrices," *Journal of Applied Polymer Science*, vol. 107, no. 1, pp. 667–673, 2008.
- [9] S. Hashemi, M. T. Gilbride, and J. Hodgkinson, "Mechanical property relationships in glass-filled polyoxymethylene," *Journal of Materials Science*, vol. 31, pp. 5017–5025, 1996.
- [10] S. Soundararajan and S. C. Shit, "Studies on properties of polyolefins: polypropylene copolymer (PPCp) blends with polyoxymethylenes (POM)," *Journal of Polymer Testing*, vol. 20, no. 3, pp. 313–316, 2001.
- [11] B. K. Kim, J. W. Seo, and H. M. Jeong, "Morphology and properties of waterborne polyurethane/clay nanocomposites," *European Polymer Journal*, vol. 39, no. 1, pp. 85–91, 2003.
- [12] A. Pegoretti, J. Kolarik, and C. Migliaresi, "Recycled poly(ethylene terephthalate)/layered silicate nanocomposites: morphology and tensile mechanical properties," *Journal of Polymer*, vol. 45, no. 8, pp. 2751–2759, 2004.
- [13] A. K. Bledzki, A. A. Mamun, and M. Feldmann, "Polyoxymethylene composites with natural and cellulose fibres: toughness and heat deflection temperature," *Composites Science and Technology*, vol. 72, no. 15, pp. 1870–1874, 2012.
- [14] X. Zhao and L. Ye, "Structure and mechanical properties of polyoxymethylene/multi-walled carbon nanotube composites," *Composites Part B: Engineering*, vol. 42, no. 4, pp. 926–933, 2011.
- [15] A. K. Das, S. Suin, N. K. Shrivastava, S. Maiti, J. K. Mishra, and B. B. Khatua, "Effect of nanoclay on the morphology and properties of acrylonitrile butadiene styrene toughened polyoxymethylene (POM)/clay nanocomposites," *Polymer Composites*, vol. 35, no. 2, pp. 273–282, 2014.
- [16] L. A. Utracki, *Polymer Alloys and Blends: Thermodynamics and Rheology*, Hanser, Munich, Germany, 1989.
- [17] M. J. Folkes and P. S. Hope, *Polymer Blends and Alloys*, Blackie Academic & Professional, Chapman & Hall, London, UK, 1st edition, 1993.
- [18] C. Creton, E. J. Kramer, C.-Y. Hui, and H. R. Brown, "Failure mechanisms of polymer interfaces reinforced with block copolymers," *Macromolecules*, vol. 25, no. 12, pp. 3075–3088, 1992.
- [19] S. J. Kim, B. S. Shin, J. L. Hong, W. J. Cho, and C. S. Ha, "Reactive compatibilization of the PBT/EVA blend by maleic anhydride," *Polymer*, vol. 42, no. 9, pp. 4073–4080, 2001.
- [20] E. Boucher, J. P. Folkers, H. Hervet, L. Léger, and C. Creton, "Effects of the formation of copolymer on the interfacial adhesion between semicrystalline polymers," *Macromolecules*, vol. 29, no. 2, pp. 774–782, 1996.
- [21] T. Wang, D. Liu, and C. Xiong, "Synthesis of EVA-g-MAH and its compatibilization effect to PA11/PVC blends," *Journal of Materials Science*, vol. 42, no. 10, pp. 3398–3407, 2007.
- [22] D. Voulgaris and D. Petridis, "Emulsifying effect of dimethyldioctadecylammonium-hectorite in polystyrene/poly(ethyl methacrylate) blends," *Polymer*, vol. 43, no. 8, pp. 2213–2218, 2002.
- [23] J. S. Hong, H. Namkung, K. H. Ahn, S. J. Lee, and C. Kim, "The role of organically modified layered silicate in the breakup and coalescence of droplets in PBT/PE blends," *Polymer*, vol. 47, no. 11, pp. 3967–3975, 2006.
- [24] M. Y. Gelfer, H. H. Song, L. Liu et al., "Effects of organoclays on morphology and thermal and rheological properties of polystyrene and poly(methyl methacrylate) blends," *Journal of Polymer Science B: Polymer Physics*, vol. 41, no. 1, pp. 44–54, 2002.
- [25] Y. Wang, Q. Zhang, and Q. Fu, "Compatibilization of immiscible Poly(propylene)/Polystyrene blends using clay," *Macromolecular Rapid Communications*, vol. 24, no. 3, pp. 231–235, 2003.
- [26] S. Sinha Ray and M. Bousmina, "Compatibilization efficiency of organoclay in an immiscible polycarbonate/ poly(methyl methacrylate) blend," *Macromolecular Rapid Communications*, vol. 26, no. 6, pp. 450–455, 2005.
- [27] S. S. Ray and M. Bousmina, "Effect of organic modification on the compatibilization efficiency of clay in an immiscible polymer blend," *Macromolecular Rapid Communications*, vol. 26, no. 20, pp. 1639–1646, 2005.
- [28] S. Sinha Ray, S. Pouliot, M. Bousmina, and L. A. Utracki, "Role of organically modified layered silicate as an active interfacial modifier in immiscible polystyrene/polypropylene blends," *Polymer*, vol. 45, no. 25, pp. 8403–8413, 2004.
- [29] B. B. Khatua, D. J. Lee, H. Y. Kim, and J. K. Kim, "Effect of organoclay platelets on morphology of nylon-6 and poly(ethylene-ran-propylene) rubber blends," *Macromolecules*, vol. 37, no. 7, pp. 2454–2459, 2004.
- [30] Y. T. Sung, Y. S. Kim, Y. K. Lee et al., "Effects of clay on the morphology of poly(acrylonitrile-butadiene-styrene) and polypropylene nanocomposites," *Polymer Engineering and Science*, vol. 47, no. 10, pp. 1671–1677, 2007.

- [31] W. Dziadur, A. Litak, S. Kuciel, and V. Tomaszewska, "Changes of microstructures PA6 and POM as result of their modification by copolymer of ethylene," in *Proceedings of the 8th Seminar Plastics in Machine Design*, pp. 91–100, Fotobit Design, Cracow, Poland, October 1997.
- [32] X. L. Ji, J. K. Jing, W. Jiang, and B. Z. Jiang, "Tensile modulus of polymer nanocomposites," *Polymer Engineering & Science*, vol. 42, no. 5, pp. 983–993, 2002.