REFERENCES

[1] Smith, W.F. Engineering Material. New York: McGrew-Hill, 1993.

[2] Thomason, J.L. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene. Composites Part A 36 (2005): 995-1003.

[3] Kim, H.B.; Choi, J.S.; Lee, C.H.; Lim, S.T.; Jhon, M.S.; and Choi, H.J. Polymer blend/organoclay nanocomposite with poly(ethylene oxide) and poly(methylene methacrylate). European Polymer Journal 41 (2005): 679-685.

[4] Chow, W.S.; Abu Bakar, A.; Mohd Ishak, Z.A.; Karger-Kocsis, J.; and Ishiaku, U.S. Effect of maleic anhydride-grafted ethylene-propylene rubber on the mechanical, rheological and morphological properties of organoclay reinforced polyamide 6/polypropylene nanocomposites. European Polymer Journal 41 (2005): 687-696.

[5] Modesti, M.; Lorenzetti, A.; Bon, D.; and Besco, S. Effect of processing conditions on morphology and mechanical properties of compatibilized polypropylene nanocomposites. Polymer 46 (2005): 10237-10245.

[6] Mishra, J.K.; Hwang, K.J.; and Ha, C.S. Preparation, mechanical and rheological properties of a thermoplastic polyolefin (TPO)/organoclay nanocomposite with reference to the effect of maleic anhydride modified polypropylene as a compatibilizer. Polymer 46 (2005): 1995-2002.

[7] Osman, M. A.; Rupp, J. E.P.; and Suter, U. W. Gas permeation properties of polyethylene-layered silicate nanocomposite. Journal of Materials Chemistry 15 (2005): 1298-1304.

[8] Zaragoza, M.V.; Vargas, E.R.; Rodriguez, F.J.; and Martinez, B.M. Thermal stability and flammabilbity properties of heterophasic PP-EP/EVA/organoclay nanocomposites. Polymer Degradation and Stability 91 (2006): 1319-1325.

[9] Burmistr, M.V.; Sukhyy, K.M.; Shilov, V.V.; Pissis, P.; Spanoudaki, A.; Sukha, I.V.; Tomilo, V.I.; and Gomza, Y.P. Synthesis, structure, thermal and mechanical properties of nanocomposites based on linear polymers and layered silicates modified by polymeric quaternary ammonium salts (ionenes). Polymer 46 (2005): 12226-12232.

[10] Dasari, A.; Yu, Z.; and Mai, Y.W. Effect of blending sequence on microstructure of ternary nanocomposites. Polymer 46 (2005): 5986-5991.

[11] Gianeli, W.; Ferrara, G.; Camino, G.; Pellegatti, G.; Rosenthal, J; and Trombini, R.C. Effect of matrix features on polypropylene layered silicate nanocomposites. Polymer 46 (2005): 7037-7046.

[12] Lertwimolnun, W.; and Vergnes, B. Influence of compatibilizer and processing conditions on the dispersion of nanoclay in a polypropylene matrix. Polymer 46 (2005): 3462-3471 36.

[13] Li, J.X.; Wu, J.; and Chan, C.M. Thermoplastic nanocomposites. Polymer 41 (2000): 6935-6937.

[14] Lebaron, P.C.; Wang, Z.; and Pinnavaia, T.J. Polymer-layered silicate nanocomposites: an overview. Applied Clay Science 15 (1999): 11-29.

[15] Zhang, Y.Q.; Lee, J.H.; Rhee, J.M.; and Rhee K.Y. Polypropylene-clay nanocomposites prepared by in situ grafting-intercalating in melt. Composites Science and Technology 64 (2004): 1383-1389.

[16] Wang, Y.; Chen, F.B.; Li, Y.C.; and Wu, K.C. Melt processing of polypropylene/clay nanocomposites modified with maleated polypropylene compatibilizers. Composites: Part B 35 (2004): 111-124.

[17] Lei, S.G.; Hoa, S.V.; and Ton-That, M.T. Effect of clay types on the processing and properties of polypropylene nanocomposites. Composites Science and Technology 10 (2005): 266-272.

[18] Solomon, M.; and Somwangthanaroj, A. Intercalated Polypropylene Nanocomposites. New York: Marcel Dekker, 2004.

[19] http://en.wikipedia.org/wiki/Fibreglass.

[20] http://www.sgva.com/business_info/marketfig.html.

[21] Ota, W.N.; Amico, S.C.; and Satvanaravana, K.G. Studies on the combined effect of injection temperature and fiber content on the properties of polypropylene-glass fiber composites. Composites Science and Technology

65 (2005): 873-881.

[22] Wambua, P.; Ivens J.; Verpoest I. Natural fibres: can they replace glass in fibre reinforced plastic. Composites Science and Technology 63 (2003) 1259-1264.

[23] Barkoula, N.M.; and Karger-Kocsis, J. Effects of fibre content and relative fibre-orientation on the solid particle erosion of GF/PP composites. Wear 252 (2002): 80-87.

[24] Sombatsompop, N.; and Chaiwattanpipat, W. Temperature profile of glass fibre-filled polypropylene melts in injection moulding. Polymer Testing 19 (2000): 713-724.

[25] Wang, W.; Tang, L.; and Qu, B. Mechanical properties and morphological structures of short glass fiber reinforced PP/EPDM composite. European Polymer Journal 39 (2003): 2129-2134.

[26] Fu, S.Y.; Lauke, B.; Mader, E.; Yue, C.Y.; and Hu, X. Tensile properties of short-glass-fiber- and short-carbon-fiber-reinforced polypropylene composites. Composites: Part A 31 (2000): 1117-1125.

[27] Hamada, H.; Fujihara, K.; and Harada, A. The influence of sizing conditions on bending properties of continuous glass fiber reinforced polypropylene composites. Composites: Part A 31 (2000): 979-990.

[28] Gullu, A.; Ozdemir, A.; and Ozdemir, E. Experimental investigation of the effect of glass fibres on the mechanical properties of polypropylene (PP) and polyamide 6 (PA6) plastics. Materials and Design 27 (2006): 316-323.

[29] Zebarjad, S.M. The influence of glass fiber on fracture behavior of isotactic polypropylene. Materials and Design 24 (2003): 531-535.

[30] Varatharajan, R.; Malhotra, S.K.; Vijayaraghavan, L.; and Krishnamurthy, R. Mechanical and machining characteristics of GF/PP and GF/Polyester composites. Materials Science and Engineering B 16 (2006): 921-924 **3.1**.

[31] Qin, H.; Zhang, S.; Zhoa, C.; Hu, G.; and Yang, M. Flame retardant mechanism of polymer/clay nanocomposites based on polypropylene Polymer 46 (2005): 8386-8395.

[32] Shentu, B.Q.; Li, J.P.; Weng, Z.X. Additive effects of N,N,N',N'-tetraalkyl terephthalamide on crystalline morphology and mechanical properties of polypropylene. Journal of Zhejiang University Science A (2006): 330-334.

APPENDICES

Appendix A

XRD data and calculation

The interlayer spacing of layered silicates in iPP/organoclay nanocomposite was calculated by Bragg's law equation as shown below.

$$n\lambda = 2d\sin\theta \qquad \text{(A-1)}$$

where n = interlayer

λ = wavelength, 1.541 Å

d = interlayer spacing between diffractional lattice planes

θ = diffraction angle

Diffraction patterns of pristine clay, organoclay powder and iPP/organoclay nanocomposite were measured by means of XRD. For example, the diffraction peak (2θ) of pristine clay was 7.01°. The interlayer spacing can be calculated as follows:

$$(1)(1.541) = 2d \sin (7.01/2)$$

$$d = 12.6 \text{ Å}$$

$$d = 1.26 \text{ nm.}$$

Table A.1 Diffraction peak and d-spacing of pristine clay, organoclay, neat iPP, iPP/GF composite and iPP/organoclay nanocomposite.

Sample	2θ (°)	d-spacing (nm)
Pristine clay	7.01	1.26
	19.77	0.45
	21.61	0.41
Organoclay	4.61	1.92
	19.79	0.45
	21.71	0.41
Neat iPP	13.77	0.64
	16.62	0.53
	18.27	0.49
	21.49	0.41
iPP/GF composite	13.95	0.63
	15.81	0.56
	16.68	0.53
	18.45	0.48
	21.64	0.41
iPP/organoclay nanocomposite	4.66	1.89
	6.84	1.29
	13.86	0.64
	16.62	0.53
	18.24	0.49
	21.64	0.41
iPP/GF : iPP/organoclay 90 : 10	4.66	1.89
	6.84	1.29
	14.03	0.63
	15.95	0.56
	16.79	0.53
	18.41	0.48
	21.67	0.41
iPP/GF : iPP/organoclay 70 : 30	4.66	1.89
	6.84	1.29
	13.83	0.64
	15.93	0.56
	16.67	0.53
	18.27	0.49
	21.55	0.41
iPP/GF : iPP/organoclay 50 : 50	4.66	1.89
	6.84	1.29
	13.87	0.64
	15.87	0.59
	16.69	0.53
	18.33	0.48
	21.51	0.41

Determination of degree of crystallinity

To determine the degree of crystallinity by means of XRD, 100 percent crystallinity was introduced to calculate degree of crystallinity of nanocomposite. In this study, nanocomposite had iPP as polymer matrix, 100 percent degree of crystallinity of iPP was determined as shown below

$$\text{Degree of crystallinity}_{iPP} = \frac{\text{Peak area of neat iPP} \times 100}{\text{Total area of iPP matrix}}$$

$$= \frac{5237.7 \times 100}{13076.3}$$

$$= 40.05$$

The peak area of composites were summarized in Table 4.1. For example, the degree of crystallinity of iPP/GF composite was determined by using above equation.

$$\text{Degree of crystallinity}_{iPP/GF} = \frac{2960.2 \times 100}{7374.9}$$

$$= 40.14$$

Appendix B

Determination of degree of crystallinity

To determine the degree of crystallinity by means of DSC, 100 percent crystallinity was introduced to calculate degree of crystallinity of nanocomposite. In this study, nanocomposite had iPP as polymer matrix 100 percent degree of crystallinity of iPP is 209 J/g. Degree of crystallinity was determined as shown below

$$\text{Degree of crystallinity} = \frac{\text{Enthalpy of crystallization}_{DSC} \times 100}{\text{Enthalpy of 100 percent crystallinity}} \times \frac{1}{\text{weight fraction of iPP}} \qquad \text{(B-1)}$$

where $\Delta H\ (100\%\text{crystallinity})_{iPP} = 209$ J/g.

The enthalpy of crystallization and degree of crystallinity of nanocomposite were summarized in Table 4.3. For example, the degree of crystallinity of iPP/GF composite as shown in Figure 4.7 was determined by using above equation.

$$\text{Degree of crystallinity} = \frac{80.25 \times 100}{209} \times \frac{1}{(90/100)}$$

$$= 44.79$$

Appendix C

Raw data of mechanical properties of iPP composites

Table C.1 Mechanical properties of neat iPP.

	Stress at break (MPa)	Tensile modulus (MPa)	Maximum stress (MPa)	Strain at Maximum Load (%)	Strain at break (%)
1	27.1	668.7	34.7	18.6	35.6
2	24.4	601.9	34.9	18.1	33.2
3	24.5	600.8	34.7	18.0	34.3
4	22.6	664.1	34.8	17.5	34.3
5	27.1	688.1	34.5	18.5	34.2
6	27.2	724.7	34.9	18.0	34.5
7	25.4	687.1	35.4	18.9	36.8
8	24.7	593.7	34.8	18.1	35.8
9	25.3	624.8	34.8	17.6	34.9
10	24.7	679.1	34. 7	17.9	34.7
Mean	**25.3**	**653.3**	**34.8**	**18.1**	**34.8**
SD	**1.5**	**45.0**	**0.2**	**0.4**	**1.0**

Table C.2 Mechanical properties of iPP/GF composite. (10 wt% GF loading)

	Stress at break (MPa)	Tensile modulus (MPa)	Maximum stress (MPa)	Strain at Maximum Load (%)	Strain at break (%)
1	37.6	966.1	40.6	10.2	14.8
2	39.2	992.3	40.7	9.9	13.0
3	37.0	991.7	39.9	10.1	13.8
4	39.4	1018.1	41.1	10.0	13.8
5	36.8	978.1	40.1	10.2	13.3
6	37.1	1046.3	40.3	10.5	15.0
7	38.0	946.5	39.9	10.6	13.3
8	37.3	1070.2	40.1	10.6	15.5
9	37.5	985.6	39.7	10.9	14.7
10	36.6	1008.3	39.3	10.8	15.1
Mean	**37.7**	**1000.3**	**40.2**	**10.4**	**14.2**
SD	**1.0**	**37.0**	**0.5**	**0.3**	**0.9**

Table C.3 Mechanical properties of iPP/organoclay nanocomposite. (3 wt% organoclay loading)

	Stress at break (MPa)	Tensile modulus (MPa)	Maximum stress (MPa)	Strain at Maximum Load (%)	Strain at break (%)
1	25.4	780.4	36.3	15.0	29.7
2	30.3	827.9	36.2	14.5	28.6
3	27.7	745.6	36.7	14.8	27.3
4	28.6	685.8	35.9	15.1	29.4
5	28.7	721.5	36.2	15.3	27.4
6	26.8	734.8	36.1	15.5	31.1
7	25.5	695.4	36.1	16.6	31.0
8	26.9	750.5	36.2	15.3	33.5
9	25.4	794.4	35.7	14.5	39.3
10	29.4	781.4	36.8	15.1	26.6
Mean	**27.5**	**751.8**	**36.2**	**15.2**	**30.4**
SD	**1.8**	**44.8**	**0.3**	**0.6**	**3.7**

Table C.4 Mechanical properties of blended composites at iPP/GF: iPP/organoclay ratios of 90:10.

	Stress at break (MPa)	Tensile modulus (MPa)	Maximum stress (MPa)	Strain at Maximum Load (%)	Strain at break (%)
1	32.5	1786.2	34.4	5.2	8.1
2	33.5	1909.9	37.5	5.0	7.9
3	32.1	1952.3	37.4	5.0	7.5
4	31.1	1879.1	36.5	5.2	7.5
5	35.3	1931.4	37.2	5.0	7.9
6	31.6	1917.0	37.1	5.1	8.3
7	31.5	1907.1	37.0	5.2	8.1
8	32.2	1915.4	37.1	5.1	8.3
9	30.5	1894.5	36.8	5.2	8.2
10	32.1	1923.3	37.0	5.2	8.7
Mean	**32.2**	**1901.6**	**36.8**	**5.1**	**8.1**
SD	**1.3**	**45.1**	**0.9**	**0.1**	**0.4**

Table C.5 Mechanical properties of blended composites at iPP/GF: iPP/organoclay ratios of 70:30.

	Stress at break (MPa)	Tensile modulus (MPa)	Maximum stress (MPa)	Strain at Maximum Load (%)	Strain at break (%)
1	32.9	1887.2	38.0	6.0	8.4
2	32.1	1825.6	37.3	5.5	8.7
3	32.1	1820.9	37.5	6.1	8.7
4	30.5	1874.1	37.2	6.2	10.1
5	32.3	1834.6	37.4	6.1	8.4
6	32.3	1800.8	37.5	5.4	7.6
7	31.9	1856.9	37.7	6.0	9.5
8	31.3	1877.2	38.0	6.0	9.0
9	31.8	1823.9	37.4	6.1	8.8
10	31.4	1833.3	37.3	6.1	8.6
Mean	**31.9**	**1843.4**	**37.5**	**5.9**	**8.8**
SD	**0.7**	**28.7**	**0.3**	**0.3**	**0.7**

Table C.6 Mechanical properties of blended composites at iPP/GF: iPP/organoclay ratios of 50:50.

	Stress at break (MPa)	Tensile modulus (MPa)	Maximum stress (MPa)	Strain at Maximum Load (%)	Strain at break (%)
1	30.6	1761.5	36.3	5.8	10.1
2	30.4	1799.9	36.8	6.4	11.3
3	31.9	1782.3	36.7	5.7	9.2
4	31.5	1769.7	36.6	5.7	9.2
5	30.8	1753.0	36.5	6.5	10.0
6	30.3	1740.7	36.3	5.9	10.5
7	29.5	1750.3	36.2	5.9	10.1
8	29.9	1729.6	36.2	5.9	10.9
9	30.5	1739.8	36.3	5.9	9.0
10	30.4	1684.1	36.4	5.8	10.2
Mean	**30.6**	**1751.1**	**36.4**	**6.0**	**10.0**
SD	**0.7**	**31.6**	**0.2**	**0.3**	**0.8**

VITAE

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