

IV. Conclusion

A different series of polyurethane-organoclay nanocomposites were synthesized by two ways. The first way is the in-situ polymerization which includes intercalation of tyramine or 12-aminododecanoic acid onto montmorillonite clay followed by addition of diol, diamine and toluene diisocyanate. The second way is free radical polymerization of vinyl-groups-endcapped polyurethane with vinyl-monomer-clay. The infrared (IR) spectroscopy confirms the interaction between the polymer and silicate layers. The XRD illustrates that the d-spacing which increased to more than 44 Å since there is no peak corresponding to d_{001} with small ratios of organoclay (≈ 5 wt-%) leading to exfoliation. While exfoliation/intercalation was found with the higher ratios of organoclay (7-20 wt-%), since a low intensity and broad peaks were observed. The morphological structure of the materials was investigated. The SEM images which confirmed the dispersion of nanometer silicate layers in the polyurethane matrix.

The presence of organoclay has led to an improvement in the mechanical properties. Since, the tensile strength increased by 194 % with increasing the organoclay contents up to 20% compared to the PU with 0% organoclay. The results of tensile strength of PU/SMA/ALA-MMT nanocomposites are higher than the corresponding PU/Tyr-MMT and PU/vinyl monomer-MMT by 6-7 times. Also, it was found that the elongation decreases with increasing the organoclay contents in case of the two series PU/SMA/ALA-MMT and PU/Tyr-MMT, due to stiffness of the film samples. While in case of the third series (PU/vinyl monomer-MMT) the elongation was increased with increasing the organoclay contents, which can be attributed to both complete exfoliation of MMT in the polymer matrix and flexibility.

Summary

obeykandl.com

This thesis contains three main parts includes the introduction, experimental part, and results discussion. In addition, it contains the conclusion, references, english summary and arabic summary.

The first part, Introduction: it includes background, chemistry, structure and uses of polyurethane. Also, it contains the types and preparation of composite materials, and some details about PU-clay nanocomposites which have been reported.

The second part, Experimental: it contains a complete description of the materials, instruments, measurements and the preparation methods of the intercalation of surfactant or vinyl monomer salts onto montmorillonite clay. The preparations of PU-clay nanocomposites by in-situ polymerization of different modified-clay with different diols and/or diamine and styrene-co-maleic anhydride have been described. Also, PU-clay nanocomposites were prepared via solution polymerization of vinyl monomer-MMT and acrylate terminated PU. The formation PU-clay hybrid films and measurement of IR, TGA, SEM, tensile strength and elongation were also, described.

The third part, Results & Discussion: it includes the data obtained from the characterization methods that have been reported for all polymer-clay hybrids. The characterization of the prepared materials was investigated by different testing methods that confirm the intercalation of modifiers within the clay interlayers as illustrated by IR spectra. The TGA of the incorporated polymer within clay layers shows higher thermal stability than virgin polymers. The swelling measurements in different organic solvents and water show highly decrease or disappearance the swelling properties of PU-clay hybrids. This may reflect the improvement in the solvent resistance of the prepared materials. The X-ray diffraction illustrates that grafted

polyurethane-organoclay gave completely exfoliated nanocomposites with all modified-clay. The SEM results confirm the homogenous dispersion of nanometer silicate layers in the polyurethane matrix, i.e. the clay was completely exfoliated in the polyurethane matrix. It was also found that the presence of organoclay leads to an improvement in the mechanical properties. Since, the tensile strength is increased with increasing the organoclay contents up to 20% by the ratio 194% in compared to the PU with 0% organoclay. The results show that the tensile strength of PU/SMA/ALA-MMT nanocomposites was high by 6-7 times than the corresponding PU/Tyr-MMT and PU/vinyl monomer-MMT. Also, the elongation is decreased with increasing the organoclay contents in case of the two series PU/SMA/ALA-MMT and PU/Tyr-MMT.

V. References

1. Petrovic, Z. S. and Ferguson, J., "Polyurethane Elastomers", *Prog. Polym.Sci*, **16**, 695, 1991
2. Gum, W. F.; Wolfram, R. and Ulrich, H., "Reaction Polymers Polyurethanes Epoxides, Unsaturated Polyesters, Phenolics, Special Monomers, and, Additives; Chemistry, Technology, Applications, Markets", Hanser: 1992
3. Oertel, G.; "Polyurethane Handbook", 2ed. Hasner Gardner Publications, Inc.: Cincinnati, 1993.
4. Ikkai, F.; Shibayama, M.; kashihara, H. and Nomura, S.; "SAXS and Dynamic Viscoelastic Studies on Segmented Polyurethaneurea Solutions", *Polmer*, **38**, 769, 1997.
5. Wu, L.; Li, D.; You, B. and Qian, F., "Change in Mechanical Properties, Composition, and Structure of Hydrated Polyurethane", *J. Appl. Polym. Sci.*, **80**, 252, 2001.
6. Wu, L.; You, B.; Li, D. and Qian, F., "Effect of Hydration on the Mechanical Properties, Composition and Molecular Weight of Polyurethaneureas", *Polym. Int.*, **49**, 1609, 2000.
7. Ma, J.; Zhang, S. and Qi, Z., "Synthesis and Characterization of Elastomeric Polyurethane/Clay Nanocomposites", *J. Appl. Polym. Sci.*, **82**, 1444, 2001.
8. Wang, C. B. and Cooper, S. L., "Morphology and Properties of Segmented Polyether Poly(urethane-urea)", *Macromolecules*, **16**, 775, 1983.
9. Paik Sung, C. S. and Smith, T. W., "Properties of Segmented Polyether Poly(urethane-urea) Based on 2, 4-Toluene Diisocyanate. 2. Infrared and Mechanical Studies", *Macromolecules* **13**, 117, 1980.

10. Garrett, J. T.; Siedlecki, C. A. and Runt, J., "Microdomain Morphology of Poly(urethane-urea) Multiblock Copolymers", *Macromolecules*, **34**, 7066 , 2001
11. Ishihara, H.; Kimura, I.; Saito, K. and Ono, H., "Infrared Studies on Segmented Poly(urethane-urea) Elastomers", *J. Macromol. Sci. Phys.*, **10**, 591, 1974.
12. Petrovic, Z. S.; Ilavsky, M.; Dusek, K.; Vidakovic, M.; Javni, I. and Banjanin, B., "The Effect of Crosslinking on Properties of Polyurethane Elastomers", *J. Appl. Polym. Sci.*, **42**, 391, 1991.
13. Chiou, B.S. and Schoen, P. E., "Effects of Crosslinking of Thermal and Mechanical Properties of Polyurethanes", *J. Appl. Polym. Sci.*, **83**, 212, 2002.
14. Huang, J. and Zhang, L., "Effects of NCO/OH Molar Ratio on Structure and Properties of Graft-Interpenetrating Polymer Networks from Polyurethane and Nitrolignin", *Polymer*, **43**, 2287, 2002.
15. Petrovic, Z. S.; Javni, I. and Banhegyi, G., "Mechanical and Dielectric Properties of Segmented Polyurethane Elastomer Containing Chemical Crosslinks in the Hard Segments", *J. Polym. Sci., Part B: Polym. Phys.*, **36**, 237, 1998.
16. Petrovic, Z. S.; Javni, I. and Divjakovic, V., "Structure and Physical Properties of Segmented Polyurethane Elastomers Containing Chemical Crosslinks in the Hard Segments", *J. Polym. Sci., Part B: Polym. Phys.*, **36**, 221, 1998.
17. Senich, G. A. and Macknight, W. J., "Fourier Transform Infrared Thermal Analysis of a Segmented Polyurethane", *Macromolecules*, **13**, 106, 1980.
18. Mark, J. E.; Eisenberg, E.; Graessley, W.W.; Mandelkern, L. and

- Koenig, J.L., "The Rubber Elastic State", in "Physical Properties of Polymers, *American Chemical Society: Washington*, **1**, 1984
19. Eirich, F. R., "Science and Technology of Rubber", *Academic Press: New York*; p 419, 1978.
 20. Usuki, A.; Kawasumi, M.; Kojima, Y.; Okada, A.; Fukushima, Y.; Kurachi, T. and Kamigaito, O., "Synthesis of Nylon 6-Clay Hybrid", *J. Mater. Res.*, **8**, 1179, 1993.
 21. Lan, T. and Pinnavaia, T. J., "Clay Reinforced Epoxy Nanocomposites", *Chem. Mater.*, **6**, 2216, 1994.
 22. Qutubuddin, S. and Fu, X., "Polymer-Clay Nanocomposites: Synthesis and Properties", in *Nanosurface Chemistry*, M. Rosoff, (ed.), Marcel Dekker, p. 653, 2001.
 23. Ray, S. and Okamoto, M., "Polymer/layered silicate nanocomposites: a review from preparation to processing", *Prog. Polym. Sci.*, **28**, 1539, 2003.
 24. Vaia, R.A.; Ishii, H. and Giannelis, E. P., "Synthesis and Properties of Two Dimensional Nanostructures by Direct Intercalation of Polymer Melts in Layered Silicates", *Chem. Mater.*, **5**, 1694, 1993.
 26. Alexandre, M. and Dubois, P., "Polymer-Layered Silicate Nanocomposites: preparation, properties and uses of a new class of materials", *Mat. Sci. Eng.*, **28**, 1, 2000.
 27. Yariv, S.; Cross, H., (eds.) "Organo-Clay Complexes and Interactions", Marcel Dekker, New York, 2002.
 28. Van Olphen, H., "An introduction to Clay Colloid Chemistry", 2nd ed., Wiley, New York, 1973.
 29. Kojima, Y.; Kawasumi, M.; Usuki, A.; Okada, A.; Fukushima, Y.; Kurachi, T. and Kamigaito, O., "Mechanical Properties of Nylon 6-

- Clay Hybrid", *J. Mater. Res.*, **8**, 1185, 1993.
30. Fu, X. and Qutubuddin, S., "Synthesis of polystyrene-clay nanocomposites", *Mater. Lett.*, **42**, 12-15, 2000.
 31. LeBaron, P.; Wang, Z. and Pinnavaia, T., "Polymer-layered silicate nanocomposite: an overview", *Appl. Clay Sci.*, **15**, 11, 1999.
 32. Vaia, R.; Price, G.; Ruth, P. and Nguyen, H.; Lichtenhan, J., "Polymer/layered silicate nanocomposites as high performance ablative materials", *Appl. Clay Sci.*, **15**, 67, 1999.
 33. Giannelis, E., "Polymer-layered silicate nanocomposites: synthesis, properties and application", *Appl. Organomet. Chem.*, **12**, 675, 1998
 34. Yano, K.; Usuki, A.; Okada, A.; Kurauchi, T. and Kamigaito, O., "Synthesis and Properties of Polyimide-clay Hybrid", *J. Polym. Sci. A: Polym. Chem.* **31**, 2493, 1993.
 35. Lan, T.; Kaviratna P. and Pinnavaia, T., "On the Nature of Polyimide-Clay Hybrid Composites", *Chem. Mater.*, **6**, 573, 1994.
 36. Messersmith, P. and Giannelis, E., "Synthesis and Barrier Properties of Poly(ϵ -Caprolactone)-Layered Silicate Nanocomposites", *J. Polym. Sci. A: Polym. Chem.* **33**, 1047, 1995.
 37. Matayabas, J.; Turner, S.; In Pinnavaia T. and Beall, G. (eds.) "Polymer-clay nanocomposites", *New York: Wiley*, 207, 2001
 38. Yano, K.; Usuki, A. and Okada, A., "Synthesis and Properties of Polyimide-clay Hybrid Films", *J. Polym. Sci. A: Polym. Chem.* **35**, 2289, 1997.
 39. Bharadwaj, R.; Mehrabi, A.; Hamilton, C.; Trujillo, C.; Murga, M.; Fan, R.; Chavira, A. and Thompson, A., "Structure-property relationship in crosslinked polyester clay nanocomposites", *Polymer*, **43**,

- 3705, 2002.
40. Giannelis, E., "Polymer Layered Silicate Nanocomposites", *Adv. Mater.*, **8**, 29, 1996.
 41. Ray, S.; Okamoto, K. and Okamoto, M.; "Structure-Property Relationship in Biodegradable Poly(butylenes succinate)/Layered Silicate Nanocomposites", *Macromolecules*, **36**, 2355, 2003.
 42. Ray, S.; Yamada, K.; Okamoto, M.; Fujimoto, Y.; Ogami, A. and Ueda, K., "New Polylactide/Layered Silicate Nanocomposites. Designing of materials with desired properties", *Polymer*, **44**, 6633, 2003.
 43. Avena, M. and De Pauli, C., "Effect of Structural Charges on Proton Adsorption at Clay Surfaces", in *"Geochemical and Hydrological Reactivity of Heavy Metals in Soils"*, Selim, H. and Kingery, W. (eds.) Lewis Publishers p.79, 2003.
 44. Pinnavaia, G. and Ball, G. (eds), "Polymer Clăy Nanocomposites", New York: Wiley, 124, 2000.
 45. Lange, J. and Wyser, Y., "Recent Innovations in Barrier Technologies for Plastic Packaging a Review", *Packag. Techn. Sci.*, **16**, 149, 2003.
 46. Rohl, W.; Rybinski, W. and Schwuger, M., "Adsorption of Surfactants on lowcharged layer Silicates Part I: Adsorption of Cationic Surfactants", *Prog. Colloid Polym. Sci.*, **84**, 206, 1991.
 47. Theng, B.K.G. (ed.) "Formation and Properties of Clay-Polymer Complexes", *Elsevier, New York*, 1979.
 48. Jones, T. R., "The Properties and Uses of Clays which Swell in Organic-Solvents", *Clay Minerals*. **18**, 399, 1983.
 49. Peker, S.; Yapar, S. and Besun, N., "Adsorption Behavior of a

- Cationic Surfactant on Montmorillonite", *Colloids and Surf*, **104**, 249, 1995.
50. Chen, G.; Han, B. and Yan, H., "Interaction of Cationic Surfactants with Iron and Sodium Montmorillonite Suspensions", *J. Colloid Interface Sci.*, **201**, 158, 1998.
 51. Parfitt, G.D. (ed.), "Dispersion of Powders in Liquids," *Applied Science Publisher, New Jersey*, 1981.
 52. Fu, X. and Qutubuddin, S., "Polymer-Clay Nanocomposites: Exfoliation of Organophilic Montmorillonite Nanolayers in Polystyrene", *Polymer*, **42**, 807, 2001.
 53. Carrado, K., "Polymer-Clay Nanocomposites", in *Advanced Polymeric Materials*, Shonaike, G. and Advani, S. (edit.), CRC Press, Boca Raton, 349, 2003.
 54. Usuki, A.; Kawasumi, M.; Kojima, Y.; Okada, A.; Kurachi, T. and Kamigaito, O., "Swelling Behavior of Montmorillonite Cation Exchanged for ω -aminoacids by ϵ -caprolactam", *J. Mater. Res.*, **85**, 1174, 1993.
 55. Yasue, K.; Katahira, S.; Yoshikawa, M. and Fujimoto, K., "In situ Polymerization route to Nylon 6-clay Nanocomposites", in "Polymer-Clay Nanocomposites", Pinnavaian T.J.; Beall, G., (eds), *John Wiley & Sons, New York*, 2000.
 56. Cho, J. and Paul, D., "Nylon 6 nanocomposites by melt compounding", *Polymer*, **42**, 1083, 2001.
 57. Dennis, H.; Hunter, D.; Chang, D.; Kim, S.; White, J.; Cho, J. and Paul, D., "Effect of Melt Processing Conditions on the Extent of Exfoliation in Organoclay-based Nanocomposites", *Polymer*, **42**, 9513, 2001.

58. Akelah, A. and Moet, A., "Polymer-Clay Nanocomposite: Free-Radical Grafting of Polystyrene on to Organophilic Montmorillonite Interlayers", *J. Mater. Sci.*, **31**, 3589, 1996.
59. Doh, J. and Cho, I., "Synthesis and Properties of Polystyrene-organoammonium Montmorillonite hybrid", *Polym. Bull.*, **41**, 511, 1998.
60. Weimer, M.; Chen, H.; Giannelis, E. and Sogah, D., "Direct Synthesis of Dispersed Nanocomposites by in Situ Living Free Radical Polymerization Using a Silicate anchored Initiator", *J. Am. Chem. Soc.*, **121**, 1615, 1999.
61. Vaia, R.; Jandt, K.; Kramer, E. and Giannelis, E., "Microstructural Evolution of Melt Intercalated Polymer-Organically Modified Layered Silicate Nanocomposites", *Chem. Mater.*, **8**, 2628, 1996.
62. Vaia, R.; Jandt, K.; Kramer, E. and Giannelis, E., "Kinetics of Polymer Melt Intercalation", *Macromolecules*, **28**, 8080, 1995.
63. Vaia, R. and Giannelis, E., "Polymer Melt Intercalation in Organically-Modified Layered Silicates: Model Predictions and Experiment", *Macromolecules*, **30**, 8000, 1997.
64. Noh, M. and Lee, D., "Synthesis and Characterization of PS-Clay Nanocomposite by Emulsion Polymerization", *Polym. Bull.*, **42**, 619, 1999.
65. Kelly, P.; Akelah, A.; Qutubuddin, S. and Moet, A., "Reduction of Residual Stress in Montmorillonite/Epoxy Compounds", *J. Mater. Sci.*, **29**, 2274, 1994.
66. Akelah, A.; Kelly, P.; Qutubuddin, S. and Moet, A., "Synthesis and Characterization of Epoxyphilic Montmorillonites", *Clay Miner.*, **29**, 169, 1994.

67. Wang, M. and Pinnavaia, T.J., "Clay-Polymer Nanocomposite Formed from Acidic Derivatives of Montmorillonite and an Epoxy Resin", *Chem. Mater.*, **6**, 468, 1994.
68. Lan, T.; Kaviratna, P. and Pinnavaia, T., "Mechanism of Clay Tactoid Exfoliation in Epoxy-Clay Nanocomposites", *Chem. Mater.*, **7**, 2144, 1995.
69. Kawasumi, M.; Hasedawa, N.; Kato, M.; Usuki, A. and Okada, A., "Preparation and Mechanical Properties of Propylene-Clay Hybrids", *Macromolecules*, **30**, 633, 1997.
70. Kato, M.; Usuki, A. and Okada, A., "Synthesis of Polypropylene Oligomer-Clay Intercalation Compounds", *J. Appl. Polym. Sci.*, **63**, 1781, 1997.
71. Hasegawa, N.; Okamoto, H.; Kato, M. and Usuki, A., "Preparation and Mechanical Properties of Polypropylene-Clay Hybrids based on Modified Polypropylene and Organophilic Clay", *J. Appl. Polym. Sci.*, **78**, 1918, 2000.
72. Lee, D.C. and Jang, L.W., "Preparation and Characterization of PMMA-Clay Hybrid Composite by Emulsion Polymerization", *J. Appl. Polym. Sci.*, **61**, 1117, 1996.
73. Chen, G.; Chen, X.; Lin, Z.; Ye, W. and Yao, K., "Preparation and Properties of PMMA/Clay Nanocomposite", *J. Mater. Sci. Letters*, **18**, 1761, 1999.
74. Okamoto, M.; Morita, S.; Taguchi, H.; Kim, Y.H.; Kotaka, T. and Tateyama, H., "Synthesis and Structure of Smectic Clay/Poly(Methyl Methacrylate) and Clay/Polystyrene Nanocomposite via in situ Intercalative Polymerization", *Polymer*, **41**, 3887, 2000.
75. Bandyopadhyay, S.; Giannelis, E. and Hsieh, A., "Thermal and

- Thermo-Mechanical Properties of PMMA Nanocomposites", *Polym. Mater: Sci. Eng.*, **82**, 208, 2000.
76. Bandyopadhyay, S.; Giannelis, E. and Hsieh, A., "PMMA, Nanocomposites Synthesized by Emulsion Polymerization", In: R. Krishnamoorti, R. Vaia, (Eds.), *Polymer Nanocomposites: Synthesis, Characterization, and Modeling, ACS Symposium, American Chemical Society, San Francisco*, 15, 2002.
 77. Huang, X. and Brittain, W., "Synthesis of a PMMA-Layered Silicate Nanocomposite by Suspension Polymerization", *Polym. Prepr*, **41**, 521, 2000.
 78. Huang, X. and Brittain, W., "Synthesis and Characterization of PMMA Nanocomposites by Suspension and Emulsion Polymerization", *Macromolecules*, **34**, 3255, 2001.
 79. Zeng, C. and Lee, L., "Poly(methyl methacrylate) and Polystyrene/Clay Nanocomposites Prepared by in-situ Polymerization", *Macromolecules*, **34**, 4098, 2001.
 80. Meneghetti, P. and Qutubuddin, S., "Synthesis of Poly(methyl methacrylate) - Clay Nanocomposites", *Chem. Eng. Commun.*, **188**, 81-89, 2001.
 81. Meneghetti, P. and Qutubuddin, S., "Synthesis of Poly(methyl methacrylate) - Clay Nanocomposite via Emulsion Polymerization using a Zwitterionic Surfactant", *Langmuir*, **20**, 3424, 2004.
 82. Mousa, A. and Karger-Kocsis, J., "Rheological and Thermodynamical Behavior of Styrene/Butadiene Rubber-Organoclay Nanocomposites", *Macromol. Mater. Eng.*, **286**, 260, 2001.
 83. Zhang, L.; Wang, Y.; Wang, Y.; Sui, Y. and Yu, D., "Morphology

- and Mechanical Properties of Clay/Styrene Butadiene Rubber Nanocomposites", *J. Appl. Polym. Sci.*, **78**, 1873, 2000.
84. Wang, Y.; Zhang, L.; Tang, C. and Yu, D., "Preparation and Characterization of Rubber Clay Nanocomposites", *J. Appl. Polym. Sci.*, **78**, 1879, 2000.
85. Ganter, M.; Gronski, W., Reichert P. and Muhlhaupt, R., "Rubber Nanocomposite: Morphology and Mechanical Properties of BR and SBR Vulcanizates Reinforced by Organophilic Layered Silicates", *Rubber Chem. and Technol.*, **74**, 221, 2001.
86. Ganter, M.; Gronski, W.; Semke, H. and Zlig, T.; Thomann, C.; Muhlhaupt, R., "Surface-Compatibilized Layered Silicates: A Novel Class of Nanofillers for Rubbers with Improved Mechanical Properties", *Kautsch. Gummi Kunstst.*, **54**, 166, 2001.
87. Schon, F.; Thomann, R. and Gronski, W., "Shear Controlled Morphology of Rubber/Organoclay Nanocomposite and Dynamic Mechanical Analysis", *Macromol. Symp*, **189**, 105, 2002.
88. Schon, F. and Gronski, W., "Filler Networking of Silica and Organoclay in Rubber Composites: Reinforcement and Dynamic-Mechanical Properties", *Kautsch. Gummi Kunstst.*, **56**, 166, 2003.
89. Sadhu, S. and Bhowmick, A., "Effect of Chain Length of Amine Nature and Loading of Clay on Styrene-Butadiene Rubber-Clay Nanocomposites", *Rubber Chem. and Technol.*, **76**, 860, 2003.
90. Kojima, Y.; Usuki, A.; Kawasumi, M.; Okada, A. and Fukushima, Y., "Mechanical Properties of Nylon 6-Clay Hybrid", *J. Mater. Res.*, **8**, 1185, 1993.
91. Kojima, Y.; Usuki, A.; Kawasumi, M.; Okada, A.; Kurauchi, T. and Kamigaito, O., "Synthesis of Nylon 6-Clay Hybrid by

Montmorillonite Intercalated with ϵ -Caprolactam", *J. Polym. Sci., Part A: Polym. Chem.*, **31**, 983, 1993.

92. Usuki, A.; Kojima, Y.; Kawasumi, M.; Okada, A. and Fukushima, Y., "Synthesis of Nylon 6-Clay Hybrid", *J. Mater. Res.*, **8**, 1179, 1993.
93. Usuki, A.; Kawasumi, M.; Kojima, Y.; Okada, A. and Kurauchi, T., "Swelling Behavior of Montmorillonite Cation Exchanged for ω -Amino Acids by ϵ -Caprolactam", *J. Mater. Res.*, **8**, 1174, 1993.
94. Alexandre M. and Dubois, P., "Polymer-layerd silicate", *Mater.Sci. and Eng.*, **28**, 1, 2000.
95. LeBaron, P. C.; Wang, Z. and Pinnavaia, T.J., "Polymer-Layered Silicate Nanocomposites: An Overview", *Appl. Clay Sci.*, **15**, 11, 1999.
96. Chen, T.K.; Tien, Y.I. and Wei, K.H., "Synthesis and Characterization of Novel Segmented Polyurethane/Clay Nanocomposites", *Polymer*, **41**, 1345, 2000.
97. Ma, J.; Zhang, S. and Qi, Z., "Synthesis and Characterization of Elastomeric Polyurethane/Clay Nanocomposites", *J. Appl. Polym. Sci.*, **82**, 1444, 2001.
98. Ni, P.; Li, J.; Suo, J. and Li, S., "Novel Polyether Polyurethane/Clay Nanocomposites Synthesized with Organic-Modified Montmorillonite as Chain Extenders", *J. Appl. Polym. Sci.*, **94**, 534, 2004.
99. Xu, R.; Manias, E.; Snyder, A. J. and Runt, J., "New Biomedical Poly(urethane-urea)-Layered Silicate Nanocomposites", *Macromolecules*, **34**, 337, 2001.

100. Chen, T.K.; Tien, Y.I. and Wei, K.H., "Synthesis and Characterization of Novel Segmented Polyurethane/Clay Nanocomposite Via Poly(ϵ -caprolactone)/Clay", *J. Polym. Sci.: Part A Polym. Chem.*, **37**, 2225, 1999.
101. Chiang, W. Y. and chang, D.M., "Preparation and characterization of polyurethanes/allyl novolac resin simultaneous interpenetrating network", *Eur polym J.*, **31**, 709, 1995.
102. Chiang, W. Y. and Tsai, C.B, "Synthesis and properties of maleimide-terminated polyurethane AB crosslinked polymers I. Polyurethane/allyl nonyl novolac resin ABCPs", *Eur polym J.*, **35**, 1139, 1999.
103. Takeichi, T.; Guo, Y. and Agag, T., "Synthesis and characterization of poly(urethane-benzoxazine) Films as Novel type of polyurethane/phenolic resin composites", *J. Polymer Science*, **38**, 4156, 2000.
104. Cunha, F; Melo, D; Veronese, V and Forte, M., "Study of Castor Oil Polyurethane - Poly(Methyl Methacrylate) Semi- Interpenetrating Polymer Network (SIPN) Reaction Parameters", *Mater. Resear.* **7**, 539, 2004.
105. Tang, D.; Qin, C; Cai, W. and Zhao, L., "Preparation, morphology, and mechanical properties of modified-PU/UPR graft-IPN nanocomposites with BaTiO₃ fiber", *Materi.Chem. and Phys.* **82**, 77, 2003
106. Solarski, S.; Benali, S.; Rochery, M.; Devaux, E.; Alexandre, M.; Monteverde, F. and Dubois, P., "Synthesis of a Polyurethane/Clay Nanocomposite Used as Coating: Interactions Between the Counterions of Clay and the Isocyanate and Incidence on the

- Nanocomposite Structure", *J. Appl. Polym. Sci.*, **95**, 238–244, 2005
107. Sreedhar, B.; Chattopadhyay, D. K. and Swapnal, V., "Thermal and Surface Characterization of Polyurethane–Urea Clay Nanocomposite Coatings", *J. Appl. Polym. Sci.*, **100**, 2393, 2006
108. Wang, J.; Chen, Y. and Wang, J., "Preparation and Properties of a Novel Elastomeric Polyurethane/Organic Montmorillonite Nanocomposite", *J. Appl. Polym. Sci.*, **99**, 3578, 2006.
109. Zhang. H.; Wang.B.; Li-Hongtu; Jiang. Y and Wang. J, "Synthesis and characterization of nanocomposites of silicon dioxide and polyurethane and epoxy resin interpenetrating network", *Polym. Int.*, **52**, 1493, 2003.
110. Zhou. S.; Wu. L.; Sun.J. and Shen. W., "The change of the properties of acrylic-based polyurethane via addition of nano-silica Progress in Organic Coatings", *Prog. Org. Coat.* **45**, 33, 2002.
111. Petrovic. Z. and Zhang. W., "Glassy and Elastomeric polyurethanes filled with nano-silica particles", *Mater. Sci. Forum.* **352**, 171, 2000.
112. Petrovic. Z.S and Javni – I; Waddon. Q., *Annual Technical – conference ANTEC, Conference Proceedings*, **2**, 2390, 1998.
113. Chen. Y.; Zhou. S.; Yang. H; Gu. G and Wu. L., "Preparation and characterization of nanocomposite polyurethane", *J.Colloid Interface Sci.* **279**, 370, 2004.
114. Devaux, E.; Rochery, M. and Bourbigot. S., "Polyurethane/clay and polyurethane/POSS nanocomposites as flame retarded coating for polyester and cotton fabrics", *Fire and Materials*, **26**, 149, 2002.
115. Neumann, D., M. Fisher, L. Tran, and J.G. Matisons, "Synthesis and characterization of an isocyanate functionalized polyhedral oligosilsesquioxane and the subsequent formation of an organic-

- inorganic hybrid polyurethane", *J. Am Cheml Soc*, **124**, 13998, 2002.
116. Ping, N.; Jing, Li.; Suo, J. and Shuben, Li., "Novel polyether polyurethane/clay nanocomposites synthesized with organic-modified montmorillonite as chain extenders", *J. Appl. Polym. Sci.*, **94**, 534, 2004.
117. Choi, W. J.; Kim, S. H.; Jin, K. Y. and Kim, S.C., "Synthesis of chain-extended organifier and properties of polyurethane/clay nanocomposites", *Polymer*, **94**, 6045, 2004.
118. Hsu, S. H. and Chou, C. W., "Enhanced biostability of polyurethane containing gold nanoparticles. Polymer Degradation and Stability", *Polym. Degrad. and Stab*, **85**, 675, 2004.
119. Phadtare. S.; Kumar. A.; Vinod. V. P.; Dash. C.; Palaskar. D. V.; Rao., Shukla. P. G., Sivaram. S. and Sastry. M., "Direct Assembly of Gold Nanoparticle "Shells" on Polyurethane Microsphere "Cores" and Their Application as Enzyme Immobilization Templates", *Chemistry of Materials*, **15**, 1944, 2003.
120. Yang. Z. and Duo. X. S., "Preparation of silicon dioxide/polyurethane nanocomposites by a sol-gel process", *J. Appl. Polym. Sci.*, **92**, 2013, 2004.
121. Pattanayak. A. and Jana. S.C., " Thermoplastic Polyurethane Nanocomposites of Reactive Silicate Clays: Effects of Soft Segments on Properties", *Polym.* **46**, 5183, 2005.
122. Kim. J. Y; Jung. W. C. and Park. K. Y. Suh. K. D., "Synthesis of Na⁺-Montmorillonite/Amphiphilic Polyurethane Nanocomposite Via Bulk and Coalescence Emulsion Polymerization", *J. Appl. Polym. Sci.* **89**, 3130 2003.

123. Tien. Y. and Wei. K., "Synthesis of Na⁺-montmorillonite/amphiphilic polyurethane nanocomposite via bulk and coalescence emulsion polymerization", *J Polym Sci.*, **34**, 9045, 2001.
124. Osman. M. A.; Mittal. V.; Morbidelli. M. and Suter. U. W., "Polyurethane Adhesive Nanocomposites as Gas Permeation Barrier", *Macromolecules*, **36**, 9851, 2003.
125. Chang. J.H. and An.Y., "Nanocomposites of Polyurethane with Various Organoclays: Thermomechanical Properties, Morphology, and Gas Permeability", *J. Polym Sci, Part B: Polym Phys.*, **40**, 670, 2002.
126. Takeichi. T. and Guo. Y., "Synthesis and characterization of poly(urethane-benzoxazine)/clay hybrid nanocomposites", *J.Appl. polym. Sci.*, **90**, 4075, 2003.
127. Xiong. J.; Liu. Y.; Yang. X. and Wang. X. "Thermal and mechanical properties of polyurethane/ montmorillonite nanocomposites based on a novel reactive modifier", *Polym. Degrade. Stab*, **86**, 549, 2004.
128. Song. M.; Hourston. D. J.; Yao. K. J.; Tay. K. H. and Ansari far. M. A., "High performance nanocomposites of polyurethane elastomer and organically modified layered silicate", *J.Appl. Polym. Sci.*, **90**.3239, 2003.
129. Han. B.; Cheng. A.; J. G.; Wu. S. and Shen. W., "Effect of organophilic montmorillonite on polyurethane/montmorillonite nanocomposites", *J. Appl. Polym. Sci.*, **91**, 2536, 2004.
130. Ma. X. and Liang. G., "Plastics Manufacture and Processing", *Journal CA Section*. **37**, 655, 2003.
131. Pattanyak. A. and Jana. S., *Annual Technical Conference Society of*

- plastics Engineers*, **2**, 1424, 2003.
132. Song. M .and Yao. K. J.," X-ray diffraction detection of compliance in polyurethane - organoclay nanocomposites", *Mater.Sci. Technol*, **20**, 989, 2004.
 133. Hawley. M.; Orler. E.B; Wroblewski. D.A.; Hjelm. R and Brown. G.W., "Designing nanostructure particular fillers for elastomers", *Materials research Society Symposium Proceeding*, **61**, 471, 2001.
 134. Xu. R.; Manias. E.; Snyder. A. and Runt. J., "New Biomedical Poly (urethane-urea)-Layered Silicate Nanocomposites", *Macromolecules*, **34**, 337, 2001.
 135. Tien YI and Wei KH., "Hydrogen bonding and mechanical properties in segmented montmorillonite/ polyurethane nanocomposites of different hard segment ratios", *Polym.* **42**, 3213, 2001.
 136. Finnigan. B.; Martin. D.; Halley P.; Trauss. R. and Campbell. K. "Morphology and properties of thermoplastic polyurethane nanocomposites incorporating hydrophilic layered silicates", *Polymer*, **45**, 2249, 2004.
 137. Odian. G., editors. "Principle of Polymerization". *Wiley : New York*, 192, 1981.
 138. Xie, W.; Xie, R.; Pan, W.-P.; Hunter, D.; Koene, B.; Tan, L.-S., and Vaia, R., "Thermal Stability of Quaternary Phosphonium Modified Montmorillonites", *Chem. Mater*, **14**, 4837, 2002.
 139. Gorrasi, G.; Tortora, M. and Vittoria, V., "Synthesis and physical properties of layered silicates/polyurethane nanocomposites." *J. Polym. Sci. Part B: Polym Phys*, **43**, 2454, 2005.

140. T. Hatakeyama and F. XQuinn.,editor, "Thermal analysis fundamental and application to polymer science", John Wiley & sons: New York 2nd edition. P.55,1999.
141. Grim RE: "*Clay mineralogy*",.: McGraw-Hill, New York., 1968.
142. Chen, T. K.; Tien, Y. I. and Wei, K.H., "Synthesis and characterization of novel segmented polyurethane/clay nanocomposites", *Polymer*, **41**, 1345, 2000

VI. APPENDIX

1. ABBREVIATIONS

USED IN THIS THESIS

PU	Polyurethane
PUU	Poly(urethane urea)
SPUU	Segmented polyurethane urea
CEC	Cation exchange capacity
CMC	Critical micelle concentration
PP	Polypropylene
PMMA	Poly(methyl methacrylate)
MMT	Montmorillonite clay
VDAC	Vinyl benzyl diethyl dodecyl ammonium chloride
OMMT	Organophilic montmorillonite clay
DSC	Dynamic scanning calorimeter
DMAC	Dimethyl acetamide
SDS	Sodium dodecyl sulfate
SBRS	Styrene butadiene rubber
PUI	Polyurethane interpenetrating network
UPR	Unsaturated polyester resin
CTAB	Cetyltrimethyl ammonium bromide
PEG	Poly(ethylene glycol)
PPG	Poly(propylene glycol)
EPU	Electrometric polyurethane
TDI	Toluene diisocyanate
DMF	Dimethyl formamide
THF	Tetra hydrofuran

- 114 -

HEMA	2-Hydroxyethyl methacrylate
PHEMA	Poly(2-hydroxy ethyl methacrylate)
TGA	Thermogravimetric Analysis
SEM	Scanning Electron Micrograph
DTG	Derivation thermogravimetric

2. DOCUMENTS

Papers published from the thesis

- 1) Preparation and Characterization of PU-Clay Nanocomposites**
[*Polymer Composites*, 28, 108, 2007]
- 2) PU-Nanocomposites Material via *in situ* Polymerization into Organoclay Interlayers** [*Polymer for Advanced Technology*, 2007, in press]

Preparation and Characterization of Polyurethane–Organoclay Nanocomposites

Ahmed Rehab, Ahmed Akelah, Tarek Agag, Nasser Shalaby

Chemistry Department, Faculty of Science, University of Tanta, 31527 Tanta, Egypt

Nanocomposite polyurethane (PU)–organoclay materials have been synthesized via in-situ polymerization. The organoclay is first prepared by intercalation of tyramine into montmorillonite (MMT)-clay through ion exchange process. The syntheses of polyurethane–organoclay hybrid films containing different ratios of clay were carried out by swelling the organoclay into diol and diamine followed by addition of diisocyanate and then cured. The nanocomposites with dispersed and exfoliated structure of MMT were obtained as evidenced by X-ray diffraction and scanning electron microscope. X-ray diffraction showed that there is no peak corresponding to d_{001} spacing in organoclay with the ratios up to 20 wt%. SEM images confirmed the dispersion of nanometer silicate layers in the polyurethane matrix. Also, it was found that the presence of organoclay leads to improvement in the mechanical properties. The tensile strength was increased with increasing the organoclay contents to 20 wt% by 221% in comparison to the PU with 0% organoclay. POLYM. COMPOS., 28:108–115, 2007. © 2007 Society of Plastics Engineers

INTRODUCTION

Introducing the promising nanocomposite, which is described as the next great new frontier of materials science, recognized the technological development of this century. Nanocomposites are a class of composite materials having more than one solid phase with a dimension in the 1–20 nm ranges in which the reinforcing phase dimensions are in the order of nanometers [1]. Layered materials are potentially well suited for the design of hybrid nanocomposites, because their lamellar elements have high in-plane strength, stiffness, and a high aspect ratio.

Polymer–nanocomposites are a class of polymers reinforced with a small quantity (1–10% by weight) of particles with nanometric size. The polymer-layered silicate nanocomposites with polymer chain intercalating galleries of adjacent silicate layers to form exfoliated or intercalated,

which represent improved or new properties compared with bulk polymer, have attracted much interest. The significant improvement in the properties in comparison to the unmodified resin or conventional polymer–composite with inorganic fillers were observed. These properties include mechanical (modulus, strength, fracture toughness, and surface hardness) [2], barrier performance [3], thermal [4], flammability resistance [5], and solvent (or water) uptake [6]. To achieve equivalent physical properties, the conventional polymer composite must mix with more than 30–40 wt% of inorganic fillers such as talc, mica, silica, and carbon black, whereas a nanocomposite only requires the addition of a few percent if 1-nm thick layered silicate is well dispersed on a nanoscale (exfoliation).

The smectic clays [e.g. montmorillonite (MMT)] and related layered silicates are the preferred inorganic reinforcing materials for polymer nanocomposites for two important reasons: The first reason is they occur ubiquitously in nature and can be obtained in mineralogically pure form at low cost. The second reason is they exhibit a very rich intercalation chemistry, which allows them to be chemically modified and made compatible with organic polymers for dispersal on a nanometer length scale. The layered clay–polymer nanocomposites can be prepared by replacing the hydrophilic Na^+ and Ca^{2+} exchange cations of the native clay with more hydrophobic onium ion to form a polymer–clay hybrid through two ways. The first way is the intercalation of a monomer into the clay interlayer and subsequent heat treatment for polymerization (*in-situ*) [7]. The second way is the direct intercalation of a preformed polymer into the layered clay [8].

Since the development of nylon-6/clay nanocomposite by Toyota researchers [9], extensive studies on polymer–clay nanocomposites have been investigated to obtain new organic–inorganic nanocomposites with enhanced properties. The use of clay or organically modified clay as precursors for preparation of nanocomposites has been studied into various types of polymer systems including polyamide 6 [10], poly(oligooxyethylene methacrylate) [11], epoxy [12], polypropylene [13], polyacrylamide [14], polypyrrol [15], polystyrene [16], poly(*p*-phenylene vinylene) [17],

Correspondence to: A. Rehab, e-mail: tahmed@deci.tanta.edu.eg

DOI 10.1002/pc.20272

Published online in Wiley InterScience (www.interscience.wiley.com)

© 2007 Society of Plastics Engineers

poly(ethylene oxide) [18], polycaprolactone [19], and poly(methyl methacrylate) [20].

Polyurethanes (PUs) are one of the most interesting classes of synthetic elastomers that have unique properties. PU's elastomers are a family of segmented polymers with soft segments derived from polyols and hard segments from isocyanates and chain extenders. They are very versatile polymer materials and their properties can be modified by varying the PU microstructure and by dispersing inorganic fillers in PU matrix [21]. PUs have the advantages such as the best abrasion resistance, outstanding oil resistance, and excellent low-temperature flexibility. They also exhibit the widest variety of hardness and elastic moduli that just fill in the gap between plastics and rubbers. However, they show poor thermal stability and barrier property, which can be modified by clay [22].

In recent years, much attention has been focused on PU-clay nanocomposites, which represent greatly improved performance properties compared to the pristine PU [23–33]. However, there also exist some disadvantages concerning with thermal stability and solvent resistance properties. So, the present work will discuss our efforts to synthesis a new PU-MMT nanocomposites with improved thermal, mechanical, and solvent resistant PU-clay nanocomposites.

EXPERIMENTAL PART

Materials

Kunipia-F, sodium montmorillonite clay (Na^+ O-MMT) with cation exchange capacity (CEC) of 119 mequiv./100 g, was supplied by Kunimine Industry (Japan). Styrene was supplied from Aldrich and used after purification by washing with 1 M NaOH, then dried over anhydrous sodium sulphate followed by distillation under vacuum. Toluene-2,4-diisocyanate (TDI) was provided by Fluka, Germany, and having 99.5% of purity for 2,4-isomer with an m.p. of 21°C , was used as received. Jeffamine D-400 (Jf-400) [poly(oxypropylene-diamine)] was supplied from Huntsman (Denmark) and used after dehydrating by evacuation at 80°C for about 6 h just before use. Tyramine hydrochloride (Tyr) was used as obtained from Tokyo kasei. Poly(ethylene glycol) (PEG-1540) with average molecular weight of 1540 was purchased from Kock-Light Laboratories, England and was dried under vacuum at 80°C for 6 h just before use. Dimethylformamide (DMF) from Adwic (Egypt) was used after distillation and drying over A4 molecular sieve. Ethanol (from Adwic, Egypt) was used as obtained without further purification.

Preparation of Tyramine/Montmorillonite Organoclay I

The montmorillonite (10 g, ≈ 11.9 mequiv.) was swelled in 350 ml distilled water overnight with slow stirring. The tyramine hydrochloride (2.05 g, 11.82 mequiv.) dissolved in 50 ml distilled water was added slowly to the swelled

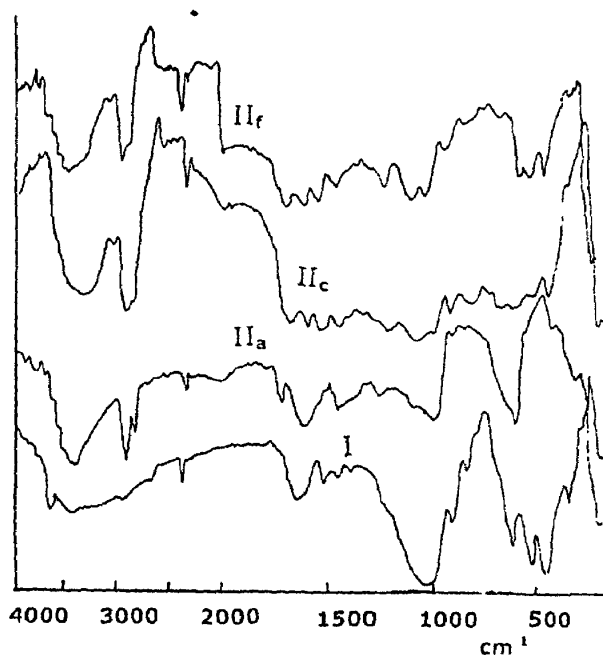


FIG. 1. IR spectra for organoclay I and PU-Tyr-MMT $\text{II}_{a..r}$.

suspended clay with vigorous stirring at 60°C . The resultant suspension was stirred overnight. The suspension was allowed to stand for a few hours followed by filtration through sintered glass (G4) and finally washed by distilled water until no white precipitate was detected on addition of AgNO_3 solution to the filtrate. The product was dried at $\sim 50^\circ\text{C}$ under vacuum to yield 11.18 g of MMT-tyramine intercalate product. The product was re-treated with tyramine by swelling in mixture of 200 ml DMF and 200 ml water followed by addition 1 g of tyramine hydrochloride solution in 10 ml distilled water, and the procedure was repeated as previously to give 11.39 g of MMT-tyramine intercalate I.

The characteristic properties were investigated by infrared (IR) (Fig. 1); thermogravimetric analysis (TGA) (Fig. 2); calcination; elemental microanalysis, swelling data Table 1; and X-ray diffraction (XRD) (Fig. 3).

Synthesis of PU-Tyr-MMT Nanocomposites $\text{II}_{a..r}$

A 16 g of dry diol (PEG-1540, 10.34 mmol) and 8.3 g of the diamine (Jf-400, 20.75 mmol) were mixed at molar ratio of 1:2, respectively and dissolved in 24.3 g of the dried DMF to give a solution (50% w/w of monomers/solvent) and it was kept as stock solution.

A 0.2105 g of the organoclay I was mixed with 8 g of the previous stock diol/diamine solution (i.e. 4 g diol/diamine) and stirred for 6 h till the mixture becomes homogenous and the organoclay completely swelled. Using the dropping funnel, 0.6 g (0.5 ml, 3.448 mmol) of TDI was added dropwise with vigorous stirring at room temperature. The reaction mixture was stirred for 8 h to give nanocomposite with 5 wt% organoclay by in-situ polymerization technique. After removing the

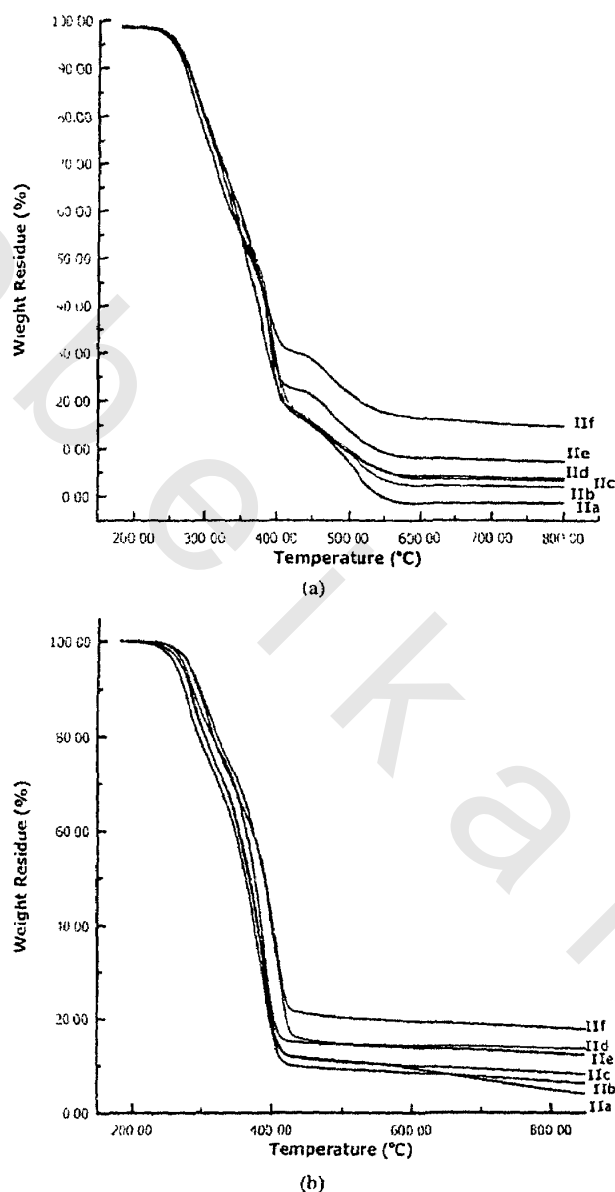


FIG. 2. (a) TGA thermograms for PU-organoclay samples (from down to top II_a, II_b, II_c, II_c, II_e, and II_f) in air. (b) TGA thermograms under argon atmosphere for PU-organoclay composites II_{a-f}.

adsorbed gases from the polymerization mixture, the PU-clay nanocomposite film II_c was formed by casting the solution in a mold and then removing the solvent at 80°C in a vacuum oven for 12 h to give elastic films.

A series of composite samples (II_{a-f}) containing different amounts (0, 3, 5, 7, 10, and 20%) of modified clay (I) were prepared by the same procedure using the same diol, diamine, and the same diisocyanate to give elastic films and the data relevant were illustrated in Table 1.

Measurements

Infrared spectra (IR) were carried out on a Perkin-Elmer 1430 ratio-recording infrared spectrophotometer using the

potassium bromide disc technique in the wavenumber range of 4000–400 cm⁻¹.

Thermogravimetric analyses (TGA) were determined with a Rigaku Thermo Plus 2 TG-DTA TG8120. The heating rate was 5°C/min in all cases in the temperature range ~30–800°C in air and under argon flow.

Calcination Measurements. A definite weight of the sample was introduced into a porcelain crucible and dried in an electric oven at 120°C overnight, then introduced into an ignition oven and the temperature was increased to 1000°C and adjusted at this temperature for 5 h. The loading of each sample was expressed as the weight loss by ignition per 100 g of the dry sample. The data of all prepared samples are listed in Table 1.

X-ray diffraction (XRD) measurements were carried out using a Rigaku RINT2000 Powder-Diffractometer equipped with a Ni-filtered Cu K α radiation ($\lambda = 1.5418$ Å at scanning rate 0.05°/sec, divergent slit 0.3°). Measurements were made for the dried product to examine the interlayer activity in the composite as prepared.

Morphology of the composite was examined by a Joel JXA-840 scanning electron microscopy (SEM) equipped with an energy dispersive X-ray detector to examine the morphology and particle size of MMT in the polymer-MMT composites. Specimen was deposited on double-sided scotch tape and examined at their fracture surface.

Mechanical properties of the samples were tested with an Instron mechanical tester [model LR5K plus (LLOYD)] at crosshead speed of 500 mm/min. The I-shaped specimens were prepared with 5 cm (5×10^{-2} m) in length, 1 cm (1×10^{-2} m) in width, and 330–450 μ m (0.33 – 0.45×10^{-3} m) in thickness. For each datum point, five samples were tested, and the average value was recorded.

The swelling degree was determined by taking a definite weight (about 0.15 g) of the dry sample and introduced into a small sintered glass and allowed to imbibe in different solvents, such as distilled water, benzene, and acetone, for 24 h. The excess solvent was removed by gentle centrifugation. The swelled sample was weighed and resuspended in the solvent. This procedure was repeated until obtaining on a constant weight for the swelled sample. The swelling degree of each sample is expressed as the amount of sorbed solvent per 100 g of dry sample.

RESULTS AND DISCUSSION

Synthesis and Structure

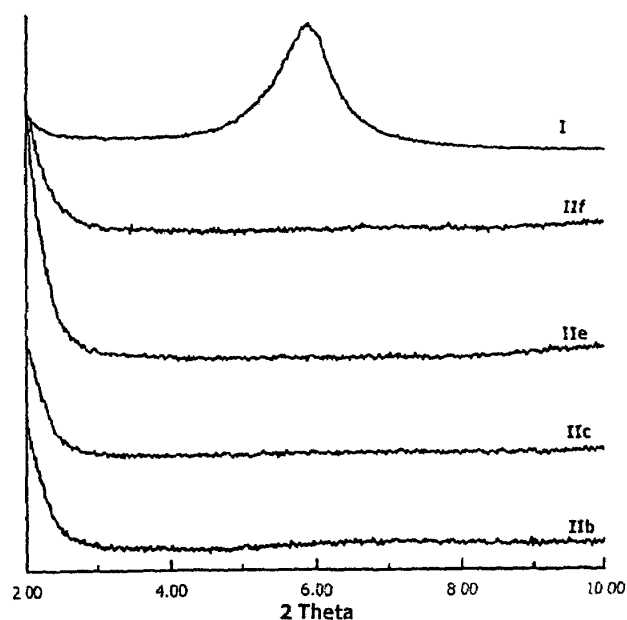
The synthesis of PU-organoclay nanocomposites was carried out through the following steps as illustrated in Scheme 1: the first step involves the modification of hydrophilic clay to become organophilic and promote the absorption of organic materials used in formation of PU and improve the particle-matrix interactions. This step was achieved through ion exchange process between sodium

TABLE 1. Thermal analysis and swelling data of PU-*vti*-MMT nanocomposites II_{a-f}

Run	Organoclay I (wt%)	TGA analysis data						Calcination ^a		Swelling data ^b		
		In air			Under argon			Clay content (%)	Organic content (%)	Water (%)	Acetone (%)	Benzene (%)
		Temperature at d-5%	Temperature at d-10%	Char yield (%)	Temperature at d-5%	Temperature at d-10%	Char yield (%)					
II _a	0	—	—	0.0	271	287	7.90	0.0	100	0.98	0.58	0.13
II _b	3	265	279	3.38	286	301	3.22	2.62	97.38	0.84	0.57	0.10
II _c	5	262	278	4.64	295	311	10.92	4.37	95.63	0.76	0.48	Nil
II _d	7	264	277	5.32	283	300	12.45	5.28	94.72	0.79	0.43	Nil
II _e	10	275	272	8.42	297	314	13.16	8.35	91.65	1.58	0.26	Nil
II _f	20	264	279	16.04	280	293	17.97	16.01	83.99	1.67	0.22	Nil

^aAt 1,000°C for 8 h.^bSwelling (%) = (weight of absorbed solvent/weight of dry sample) × 100.

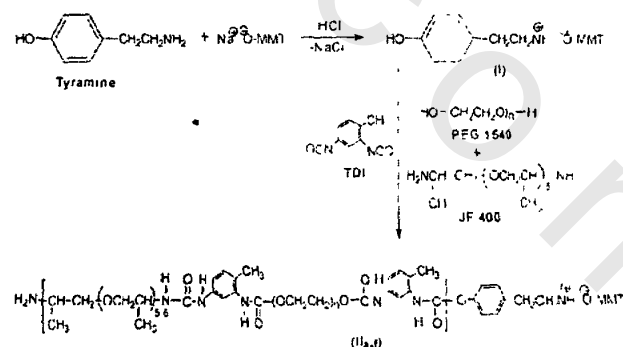
cation in MMT and ammonium groups in tyramine hydrochloride I, which contains functional group that can react with diisocyanate. The calcination indicates that the functionalization was achieved with a high degree of conversion (88%). The second step is the formation of PU nanocomposites. This step is achieved by solvation of the organoclay with the diol as PEG[b]-1540 and diamine as amine-terminated poly(oxypropylene) Jf-400. It was found that the modified clay was first swelled in the diol and diamine at room temperature, and followed by addition of the diisocyanate to produce the intercalated PUs II_{a-f}. The previous mixture was then casted in films to produce the intercalated PUs II_{a-f} films with different organoclay contents. The structural composition and properties of the prepared composite materials were determined by several analytical techniques.

FIG. 3. XRD pattern for organoclay I and PU-organoclay II_{a-f}.

The swelling data in Table 1 indicated that the swelling degrees in the polar solvents such as water and acetone are very small or there is no swelling in the nonpolar solvent such as benzene. These data reflect that there is improvement in the barrier properties of the produced materials. It was found that the materials adsorb very small quantity of the polar solvents such as water and acetone in comparison with the nonpolar solvent such as benzene, the swelling degree followed the order water ≥ acetone > benzene. Also, the data show a very small increase in the water uptake with increasing ratio of clay, which can be attributed to the higher hydrophilic characters of clay.

The IR spectra of the samples were illustrated in Fig. 1. The spectra of modified clay I shows that the reported NH stretch band near 3400 cm⁻¹ and NH bend band near 1645 cm⁻¹ are shifted quite substantially to regions associated with ⁺NH₃ vibration, which facilitate the ion exchange with MMT. A characteristic band appears at 1039, 523, and 462 cm⁻¹ for Si—O and at 3629 cm⁻¹ for OH group. The quaternary ammonium group (—N⁺≡) shows a characteristic band at 1518 cm⁻¹.

The free OH band at 3629 cm⁻¹ in organoclay I disappeared in nanocomposites indicating that the strong interaction are occurring between OH group in organoclay and



SCHEME 1. Preparation of modified clay and PU-modified clay composites.

the isocyanate forming the isocyanate linkage. It is clear that the NH_2 band near 1630 cm^{-1} in organoclay was shifted to higher wavelength near 1690 cm^{-1} with nanocomposite, which indicate that an interaction occurs between organoclay and the polymer. The spectra of PU II_a shows that the absorbance that appeared at 1729 cm^{-1} were assigned to hydrogen-bonded urethane carbonyl ($\text{C}=\text{O}$) and the one that appeared at 1453 cm^{-1} were assigned to a secondary urethane amide ($\text{C}-\text{NH}$). The spectra of the PU-organoclay II_{a-f} shows peaks at 1728 cm^{-1} due to the stretching of urethane carbonyl group ($\text{C}=\text{O}$), and at 2919 and 2864 cm^{-1} due to the asymmetric and symmetric $\text{C}-\text{H}$ stretching vibration. The 3309 cm^{-1} peak resulted from the $\text{N}-\text{H}$ group in hydrogen bonding; the main features of various bond vibrations and hydrogen bonding of these PU-modified clay nanocomposites remained the same as that of neat PU. These results deduce that there were no major chemical structural changes in PU, owing to the presence of organoclay.

Thermal Analysis

Thermal properties of PU-modified clay materials were determined by both calcination and TGA in atmospheric air and under inert condition (argon atmosphere). The data are summarized and listed in Table 1 and Fig. 2a and 2b. The data and the figures show the weight loss encountered during heating; the PU-modified clay materials were found in the range from 84 to 97% as determined by both TGA and calcination. It is clear that the weight loss evident in TGA curves is nearly compatible with the calcination measurements.

The TGA thermograms for the samples II_{a-f} in Fig. 2a indicate that there are two stages of decomposition. The first stage is the sharp and major, which involve the thermal decomposition of the polymers present on the surfaces of the clay layers and intercalated polymers into the clay. The decomposition temperature in this stage started at $\approx 260^\circ\text{C}$ and took place until $\approx 400^\circ\text{C}$, with the corresponding weight loss ranging from ≈ 65 to 80%. In this stage, the difference between the samples is very small with no order can be mentioned. The second stage is broad, in which the weight loss was ranging from ≈ 17 to 22% in the temperature range $\approx 400^\circ\text{C}$ to $\approx 570^\circ\text{C}$. In this stage, the composites displayed higher thermal resistance than pure polymers. This stage was attributed to further decomposition of the rest intercalated polymers, especially the polymers present in the interlayers of the clay or some salts in the interlayer of the clay or interval the clay mineral loses OH groups and the crystallographic structure collapsed [4]. Generally, the first stage appear that the composite samples were degraded nearly at the same temperature range and slightly faster than pure PU. This may be due to the presence of organic residues. However, in the second stage, after complete decomposition of the small organic molecules, all the nanocomposites show higher thermal resistance than pure PU matrices [28].

It was found that there are differences in the TGA analysis under argon than in air. This was explained for two reasons: the first is the presence of oxygen in air help in increasing the rates of decomposition. The second is higher thermal conductivity of air than argon, which leads to the slower decomposition rates under argon than in air as illustrated in Table 1 and Fig. 2b. The data in the Table show that the temperature at which the samples losses 5 and 10% of its weight is higher under argon than in air for all the samples. The derivation thermogravimetric (DTG) under argon for the samples II_c and II_d illustrate that the maximum rate of pyrolysis was 21.15 and 20.38% per minute at 426 and 418°C , respectively. These results indicate that the thermal properties were improved with increasing the contents of clay up to 10 wt% organoclay as illustrated in Fig. 2b in comparison with the sample with 0% clay.

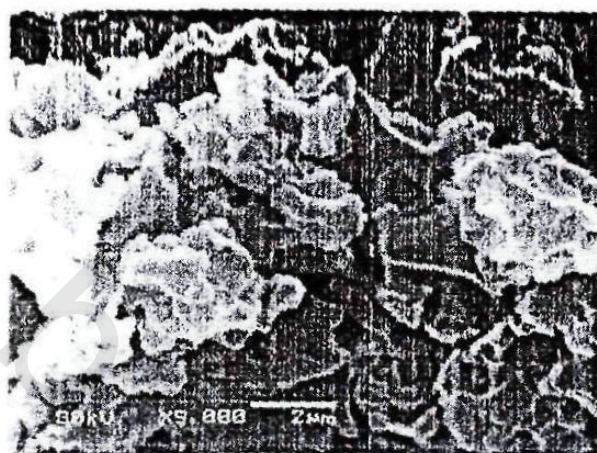
XRD Analysis

The crystal structure of MMT consists of two-dimensional layers formed by fusing two silica tetrahedral sheets to an edge-shared octahedral sheet of aluminum hydroxide. Stacking of layers of clay particles are held by weak dipolar or van der Waals forces [34]. XRD is a powerful technique to observe the extent of silicate dispersion, ordered or disordered structure in the PU nanocomposites.

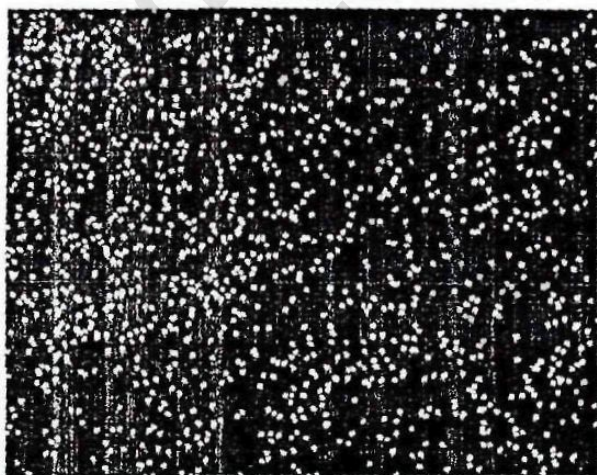
Figure 3 show typical XRD for the $\text{Na}^+/\text{O-MMT}$, organoclay I, and PU-organoclay II_{a-f} . The 001 reflection has sharp intense peak at $2\theta = 5.82^\circ$ for I. The d_{001} spacing was calculated from peak position using Bragg's law $d = \lambda/(2 \sin \theta)$. It is clear that the d -spacing for $\text{Na}^+/\text{O-MMT}$ ($2\theta = 7.18^\circ$, d -spacing = $12.34\text{ \AA}$) was increased to $15.20\text{ \AA}$, since onium group in tyramine through an ion exchange process exchanges the small inorganic Na^+ cation. Figure 3 presents XRD pattern for organoclay I and a series II_{a-f} of PU clay nanocomposites with different ratios of organoclay. The figure showed the disappearance of the peak corresponding to intercalated organoclay with all the ratios (0, 3, 5, 7, 10, and 20 wt%). This indicated that the clay was homogeneously dispersed and completely exfoliated in the PU matrix. These results confirm that modified MMT with different percentages of organoclay leads to various degree of the dispersion in the polymer matrix. These results are similar to the one described using another structures in PU nanocomposites [35].

SEM Examination

The examination of the surface of the deposition-molded samples was investigated by scanning electron microscope (SEM). Figures 4a and 5a shows micrographs of the surface at 9000 magnifications for the samples II_b and II_c as examples. The micrographs showed a homogenous dispersion of MMT in the PU matrix. The micrographs do not show the MMT particles on the micron level. The absence of MMT particles indicates that the agglomerate did not reveal the inorganic domains at the possible magnification. Also, the



(a)



(b)

FIG. 4. (a) SEM micrograph for PU-organoclay nanocomposite II_b. (b) Elemental mapping for Si of PU-organoclay nanocomposite II_b.



(a)



(b)

FIG. 5. (a) SEM micrograph for PU-organoclay nanocomposite II_a. (b) Elemental mapping for Si of PU-organoclay nanocomposite II_a.

absence of MMT aggregates was confirmed by an energy dispersion X-ray probe. An image for elemental mapping for Si was shown in Figs. 4b and 5b, in which the white dots represent uniformity dispersion of Si element. The silicon mapping shows that the mineral domains are homogeneously dispersed in the polymer matrix.

The Mechanical Behavior

The mechanical behavior of PU-organoclay nanocomposites was investigated by measuring the tensile strength and elongation at PK_{max} and at break and the results are shown in Table 2 and Fig. 6. The data in the table show increasing tensile strength with increasing clay contents. The tensile strength of II_a, which contain zero percent clay, was found to be 114 kg/cm² at PK_{max} . These values were increased to 194 kg/cm² with 5% organoclay, 215 kg/cm² with 10% organoclay, and 221 kg/cm² with 20% organoclay. Figure 6a illustrates that the tensile strength highly

affected by the clay contents especially with the small ratios of clay. The figure shows that the increasing rate of tensile strength at PK_{max} is large with small contents (3–5%) of organoclay than with the high contents. Also, the data in tables and figures show that tensile strength at break increased with the same manner as at PK_{max} with the small quantity of organoclay (3%) followed by gradual decrease with increasing the organoclay quantities. This is due to increasing brittleness and the materials start losing their mechanical properties after the point of PK_{max} .

In contrast, the data in table illustrate that the elongation at PK_{max} and at break (Fig. 6b) was decreased with increasing clay contents, due to increasing film strength. It was found that the elongation is nearly the same at PK_{max} and at break. Also, the figure show the elongation rate is large with small contents (3–5%) of organoclay than with the high contents. These data were compatible with the data obtained in our work on PU-aminolauric acid-montmorillonite nanocomposites [24].

TABLE 2 Mechanical properties data for PU-organoclay nanocomposites films II_{a-f}.

Sample	Organoclay I (wt%)	Thickness (μm)	Load cell (MPa)		Tensile strength (kg/cm ²)		Elongation (%)	
			At PK _{max}	At break	At PK _{max}	At break	At PK _{max}	At break
II _a	0	430	0.49	0.46	114	107.0	416.5	466.2
II _b	3	390	0.71	0.70	182.1	179.5	318.8	339.9
II _c	5	420	0.82	0.75	194.2	177.5	306.2	321.4
II _d	7	450	0.906	0.757	201.3	168.2	273.4	280.3
II _e	10	400	0.86	0.63	215.0	157.5	110.2	115.6
II _f	20	380	0.84	0.55	221.1	144.7	23.2	25.4

*Calculated from the relation $\text{Tensile Strength (kg/cm}^2\text{)} = \frac{\text{Force}}{\text{Area (}w \times t\text{)}} = \frac{\text{MPa} \times 10}{\text{cm}^2}$ where w is width and t is thickness of the film under test

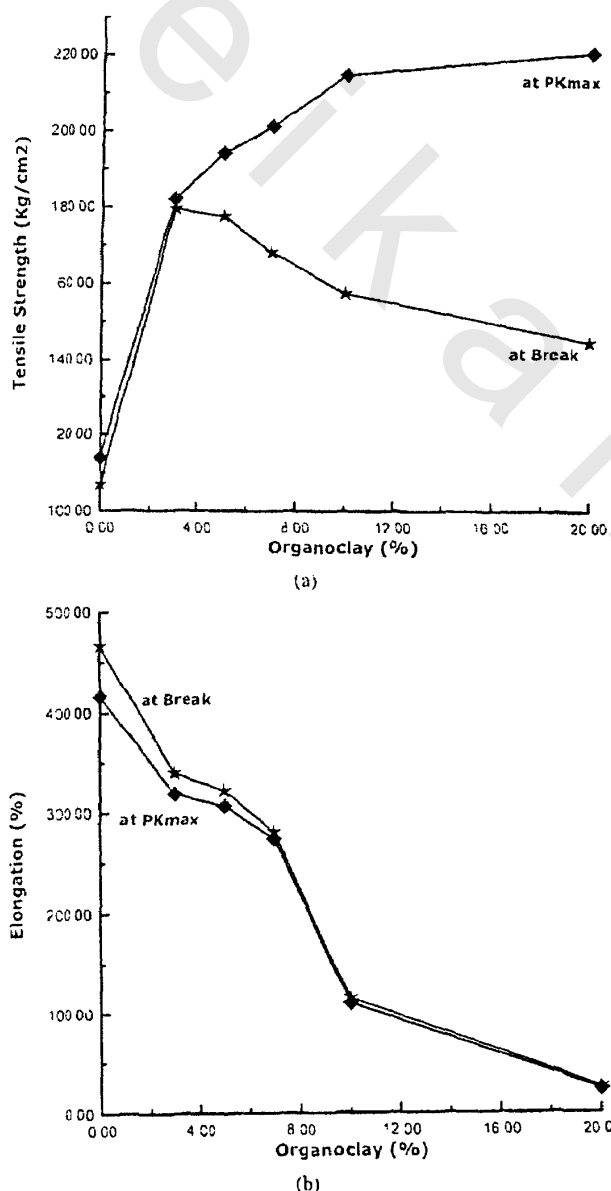


FIG. 6 (a) Tensile strength for PU-tyr-MMT nanocomposites II_{a-f} at PK_{max} and at break. (b) Elongation for PU-tyr-MMT nanocomposites II_{a-f} at PK_{max} and at break.

CONCLUSION

A series of PU-organoclay nanocomposites were synthesized by *in situ* polymerization using diol, diamine, and toluene diisocyanate in the presence of montmorillonite clay modified with tyramine. The infrared (IR) spectroscopy confirms the interaction between the polymer and silicate layers. The swelling studies show that the swelling degrees in the polar solvents such as water and acetone are very small or there is no swelling in the nonpolar solvent such as benzene. These data of swelling reflect that there is improvement in the solvent resistance property of the prepared materials. X-ray analysis showed that the *d*-spacing increased to more than 44 Å, since there is no peak corresponding to *d*₀₀₁ due to the homogeneously dispersed and exfoliated clay in the PU matrix. The SEM results confirm the dispersion of nanometer silicate layers in the PU matrix. Also, it was found that the mechanical properties were improved due to the presence of organoclay. The tensile strength increased with increasing the organoclay contents to 20 wt% by the ratio 221% relative to the PU with 0 wt% organoclay. Also, the elongation is decreased by increasing the organoclay contents due to increasing the stiffness of the films.

REFERENCES

1. R.P. Andres, S. Datta, D.B. Janes, C.P. Kubiak, and R. Reif- enberger, *The Handbook of Nanostructured Materials and Technology*, H.S. Nalwa, editor, Academic Press, Das Diego, vol. 3, Chapter 4 (1998).
2. J.W. Chao and D.R. Paul, *Polymer*, **42**, 1083 (2001).
3. G. Gorrasia, M. Tortora, V. Vittoria, E. Pollet, B. Lepoint- tevin, and M. Alexandre, *Polymer*, **44**, 2271 (2003).
4. W. Xie, R.C. Xie, W.P. Pan, D. Hunter, B. Koene, and L.S. Tan, *Chem. Mater.*, **14**, 4837 (2002).
5. J.W. Gilman, T. Kashiwagi, and J.D. Lichtenhan *J Appl Clay Sci.*, **15**, 31 (1999).
6. Y. Kojima, A. Usuki, M. Kawasumi, A. Okada, T. Kurauchi, and O. Kamigaito, *J. Appl. Polym. Sci.*, **49**, 1259 (1993).
7. (a) A. Moet and A. Akelah, *Mater. Lett.*, **18**, 97 (1993); (b) A. Rehab, A. Akelah, T. Agag, and M. Hassan, *J. Appl. Polym Sci.*, in press (2006).

8. A. Moct, A. Akelah, N. Salahuddin, A. Hiltner, and E. Baer, *Mater. Res. Soc. Symp. Proc.*, **351**, 163 (1994).
9. A. Usuki, M. Kawasumi, Y. Kojima, A. Okada, T. Kurauchi, and O. Kamigaito, *J. Mater. Res.*, **8**, 1174 (1993).
10. R.D. Davis, J.W. Gilman, and D.L. VanderHart, *Polym. Degrad. Stab.*, **79**, 111 (2003).
11. N. Salahuddin and A. Rehab, *Polym. Int.*, **52**, 241 (2003).
12. N. Salahuddin, A. Moct, A. Hiltner, and E. Baer, *Eur. Polym. J.*, **38**, 1477 (2002).
13. X. Liu and Q. Wu, *Polymer*, **42**, 10013 (2001).
14. T. Yanagisawa, C. Yokoyama, K. Kuroda, and C. Kato, *Bull. Chem. Soc. Jpn.*, **63**, 47 (1990).
15. J.W. Kim, F. Liu, H.J. Choi, S.H. Hong, and J. Joo, *Polymer*, **44**, 289 (2003).
16. J. Wang, J. Du, J. Zhu, and C.A. Wilkie, *Polym. Degrad. Stab.*, **77**, 249 (2002).
17. C.O. Oriakhi, X. Zhang, and M.M. Lerner, *Appl. Clay Sci.*, **15**, 109 (1999).
18. H.W. Chen and F.C. Chang, *Polymer*, **42**, 9763 (2001).
19. B. Lepoittevin, M. Devalckenaere, N. Pantoustier, M. Alexandre, D. Kubies, C. Calberg, R. Jérôme, and P. Dubois, *Polymer*, **43**, 4017 (2002).
20. J. Du, J. Zhu, C.A. Wilkie, and J. Wang, *Polym. Degrad. Stab.*, **77**, 377 (2002).
21. C. Zilg, R. Thomann, R. Mülhaupt, and J. Finter, *Adv. Mater.*, **11**, 49 (1999).
22. K.J. Yao, M. Song, D.L. Hourston, and D.Z. Luo, *Polymer*, **43**, 1017 (2002).
23. A. Rehab and N. Salahuddin, *Mater. Sci. Eng. A*, **399**, 368 (2005).
24. A. Rehab, A. Akelah, T. Agag, and N. Shalaby, *J. Polym. Res.*, submitted (2006).
25. A. Pattanayak and S.C. Jana, (a) *Polymer*, **46**, 3275, 3394, 5183 (2005); (b) *Polym. Eng. Sci.*, **45**, 1532 (2005).
26. S. Solarski, S. Benali, M. Rochery, E. Devaux, M. Alexandre, F. Monteverde, and P. Dubois, *J. Appl. Polym. Sci.*, **95**, 238 (2005).
27. X. Cao, L.J. Lee, T. Widya, and C. Macosko, *Polymer*, **46**, 775 (2005).
28. G. Gorrasi, M. Tortora, and V. Vittoria, *J. Polym. Sci. Part B Polym. Phys.*, **43**, 2454 (2005).
29. J.W. Xiong, Y.H. Liu, X.H. Yang, and X.L. Wang, *Polym. Degrad. Stab.*, **86**, 549 (2004).
30. S.Y. Moon, J.K. Kim, C. Nah, and Y.S. Lee, *Eur. Polym. J.*, **40**, 1615 (2004).
31. W.J. Choi, S.H. Kim, Y.J. Kim, and S.C. Kim, *Polymer*, **45**, 6045 (2004).
32. I. Rhoney, S. Brown, N.E. Hudson, and R.A. Peitrick, *J. Appl. Polym. Sci.*, **91**, 1335 (2004).
33. M. Song and K.J. Yao, *Mater. Sci. Technol.*, **20**, 989 (2004).
34. R.E. Grun, *Clay Mineralogy*, McGraw-Hill, New York (1968).
35. T.K. Chen, Y.I. Tien, and K.H. Wei, *Polymer*, **41**, 1345 (2000).

Polyurethane-nanocomposite materials via *in situ* polymerization into organoclay interlayers

Ahmed REHAB*, Ahmed AKELAH, Tarek AGAG and Nasser SHALABY

Chemistry Department, Faculty of Science, University of Tanta, Tanta, Egypt

Received 5 September 2006; Revised 5 November 2006; Accepted 8 December 2006

New nanocomposite materials based on polyurethane intercalated into organoclay layers have been synthesized via *in situ* polymerization. The syntheses of polyurethane–organoclay hybrid films were carried out by swelling the organoclay [12-aminododecanoic acid montmorillonite] into different kinds of diols followed by addition of diisocyanate then casting in a film. The homogeneous dispersion of MMT in the polymer matrix is evidenced by scanning electron microscope and x-ray diffraction, which showed the disappearance of the peak characteristic to d_{001} spacing. It was found that the presence of organoclay has improved the thermal, solvent resistance and mechanical properties. Also, the tensile strength is increased with increasing the organoclay contents to 20% by the ratio 182% related to the PU with 0% organoclay. On the contrary, the elongation has decreased with increasing the organoclay contents. Copyright © 2007 John Wiley & Sons, Ltd.

KEYWORDS: polymer composites; polyurethane-clay nanocomposites; polymer-layered silicates nanocomposite; polyurethane-organoclay hybrids; intercalated polymers

INTRODUCTION

Nanocomposites are a class of materials, which are described as the next great new frontier of materials science. These materials have the solid reinforcing phase with a dimension ranging in the order of nanometers range 1–20 nm.¹ The layered silicates as montmorillonite are the preferred inorganic materials for the design of hybrid polymer nanocomposites. This, because they can be obtained in mineralogically pure form at low cost and occur ubiquitously in nature. Also, they exhibit a very rich intercalation chemistry, which allows them to be chemically modified and made compatible with organic polymers for dispersal on a nanometer length scale.

Since the development of nylon-6/clay nanocomposite by Toyota researchers,² extensive studies on polymer/clay nanocomposites have been investigated in order to obtain new organic–inorganic nanocomposites with enhanced properties. The use of clay or organically modified clay as precursors for preparation of nanocomposites has been studied in various types of polymer systems.^{3–12}

The polymer-layered silicate nanocomposites with polymer chain intercalating galleries of adjacent silicate layers to form intercalated or exfoliated have attracted much interest. It was found as a significant improvement in the physical and mechanical properties,¹³ barrier performance,¹⁴ thermal,¹⁵ flammability resistance,¹⁶ solvent uptake,¹⁷ compared to the

unmodified resin or polymer with inorganic fillers. The polymer-MMT nanocomposites can be prepared by replacing the Na^+ or Ca^+ cations of the native clay with a hydrophobic onium ion to form organo-MMT, followed by monomer polymerization (*in situ*)¹⁸ or by direct intercalation of a preformed polymer into the organo-silicate materials.¹⁹

Polyurethanes (PUs) elastomer is one of the most interesting classes of synthetic elastomers that have unique properties. PUs elastomers are a family of segmented polymers with soft segments derived from polyols and hard segments from isocyanates and chain extenders. PUs have the advantages, such as the best abrasion resistance, outstanding oil resistance, and excellent low-temperature flexibility. They also exhibit the widest variety of hardness and elastic moduli that just fill in the gap between plastics and rubbers. However, they show poor thermal stability and barrier property, which can be modified by clay.²⁰ They are very versatile polymer materials and their properties can be modified by dispersing inorganic fillers in polyurethane matrix,²¹ to meet the demands of modern technologies such as coatings; adhesives; reaction injection molding fibers, foams, rubbers, thermoplastic elastomers, and composites.

Recently, much attention has been focused on the improved performance properties on PU-clay nanocomposites compared to the pristine PU polymer.^{22–30} The present work discusses the synthesis of PU-organoclay nanocomposites with improved physical and mechanical properties.

*Correspondence to: A. REHAB, Chemistry Department, Faculty of Science, University of Tanta, 31527 Tanta, Egypt.
E-mail: rehab220956@yahoo.com

EXPERIMENTAL PART

Materials

Sodium montmorillonite clay ($\text{Na}^{+}\text{-O-MMT}$), with cation exchange capacity (CEC) of 119 mEq/100 g, was supplied by Coniine Industry Co (Japan) under trade name Kunipia-F. Styrene was supplied from Aldrich and used after purification by washing with 1M NaOH then dried over anhydrous sodium sulfate followed by distillation under vacuum. Maleic Anhydride (from Merck-Schuchardt, Germany); 12-Aminododecanoic Acid, from Aldrich; tetrahydrofuran (THF) (from Fluka) and ethanol (from Adwic, Egypt) were used as obtained without further purification. Toluene-2,4-diisocyanate (TDI) was provided by Fluka, Germany, and having 99.5% of purity for 2,4-isomer with an m.p. 21°C , was used as received. Poly(ethylene glycol), PEG-400, with average molecular weight 400 was obtained from WINLAB laboratory chemicals, UK, was used dried under vacuum at 80°C for 6 hr just before use. Poly(ethylene glycol), PEG-1540, with average molecular weight 1540 was purchased from Crock-Light laboratories Ltd, England, was used dried under vacuum at 80°C for 6 hr just before use. Dimethylformamide (DMF) from Adwic (Egypt) was used after distillation and drying over A4 molecular sieve.

Preparation of 12-aminododecanoic acid-montmorillonite organoclay I

A 2.73 g of 12-Aminododecanoic acid (11.9 mEq.) was dissolved in 500 ml of 0.02 N HCl and added portionwise to the swelled suspension of 10 g (≈ 11.9 mEq) montmorillonite in distilled water with vigorous stirring at 60°C . The resultant suspension was stirred for overnight. The suspension was allowed to stand for a few hours followed by filtration through sintered glass (G4) and washed with distilled water until no white precipitate was detected on addition of AgNO_3 solution to the filtrate. The product was dried at $\sim 50^{\circ}\text{C}$ under vacuum to give 12.17 g of MMT-12-Aminododecanoic intercalate I. The characteristic properties were investigated by infrared (IR), thermogravimetric analysis (TGA), calcination; swelling data and x-ray diffraction (XRD).

Preparation of poly(styrene-co-maleic anhydride), PSM, II

A 10 g of pure styrene (96.2 mmol) and 9.42 g of maleic anhydride (96.2 mmol) were mixed and dissolved in 3 ml of tetrahydrofuran with stirring then 0.2 g of benzoyl peroxide was added as initiator. The solution mixture was heated at 80°C with stirring for 2 hr. The product was dissolved in 1,4-dioxane and precipitated in ethanol. The white polymer was filtered, washed with ethanol and finally dried under reduced pressure at 50°C for 12 hr to give 18.7 g of copolymer II.

IR (KBr disc): $\nu = 3447$ (C-H aromatic, stretching), 2938 (CH_2 aliphatic, stretching), 1777, 1725 (C=O), 1449, 1396 (CH_2 bending), 1219 (C-O anhydride), 953, 922, 762, 703 cm^{-1} (C-H aromatic, bending, out of plane)

Synthesis of PU-PSM-12-aminododecanoic-MMT nanocomposites III_{a-e}

A mixture of 20 g (12.987 mmol) of dry PEG-1540, 10.39 g (25.975 mmol) of PEG-400 and 3.38 g (10% by weight) of PSM II was dissolved in 33.77 g dry DMF to give solution (50% w/w of monomers/solvent).

A 0.2392 g of organoclay I was mixed with 8.9 g of the previous mixture (contains 4 g PEG-1540/PEG-400 with mole ratio 1:2) and stirred for 8 hr until the organoclay become completely swelled. To the mixture a 0.6 g (3.448 mmol) of TDI was added dropwise at room temperature with vigorous stirring. The stirring was continued for 8 hr to give nanocomposite by *in situ* polymerization technique with 5 wt % organoclay. The PU-clay nanocomposite film III_c was formed by casting the free air (gases) solution mixture in a mold and then removing the solvent under reduced pressure 80°C for 12 hr.

The other samples III_{a-e} were prepared by the same procedure and conditions with different amount (0, 1, 10% and 20%) of modified clay I and the same diols, and diisocyanate to give elastic films

Analytical procedures

Infrared spectra (IR) were carried out on a Perkin-Elmer 1430 Ratio-recording infrared spectrophotometer using the potassium bromide disc technique in the wave number range of $4000\text{--}400\text{ cm}^{-1}$.

Thermogravimetric analyses (TGA) were determined with Rigaku Thermo Plus 2 TG-DTA TG8120. The heating rate was $5\text{--}10^{\circ}\text{C}/\text{min}$. under air and argon atmosphere in the temperature range $\sim 30\text{--}900^{\circ}\text{C}$.

X-ray diffraction (XRD) was observed from an X-ray diffractometer, Rigaku RINT2000 equipped with a Ni-filtered Cu-K α radiation ($\lambda = 1.5418\text{ \AA}$) at scanning rate of 0.3 degree per minute.

Morphology of the composite was examined by a Joel JXA-840 Scanning Electron Microscopy (SEM) equipped with an energy dispersive x-ray detector to examine the morphology and particle size of MMT in the polymer-MMT composites. Specimen was deposited on double-sided scotch tape and examined at their surface.

Mechanical properties of the samples were tested with an Instron mechanical tester [model DL-35/ LR5K plus (LLOYD)] at crosshead speed of 500 mm min^{-1} . The I-shaped specimens were prepared with 5 cm ($5 \times 10^{-2}\text{ m}$) in length, 1 cm ($1 \times 10^{-2}\text{ m}$) in width, and $330\text{--}450\text{ }\mu\text{m}$ ($0.33\text{--}0.45 \times 10^{-3}\text{ m}$) in thickness. For each datum point, five samples were tested, and the average value was recorded.

Calcination Measurements: A definite weight of the sample was introduced into a porcelain crucible and dried in an electric oven at 120°C overnight, then introduced into an ignition oven and the temperature was increased to 1000°C and adjusted at this temperature for 5 hr. The loading of each sample expressed as the weight loss by ignition per 100 g of the dry sample. The data of all prepared samples are listed in Table 1.

The swelling degree was determined by taking a definite weight (about 0.15 g) of the dry sample and introduced into a small sintered glass and allowed to imbibe in different solvents (distilled water, benzene and acetone) for 24 hr. The

Table 1. Swelling and thermal analyses data of PU/SMA/ALA-MMT nanocomposites (III_{a-e})

Sample	I (%)	Swelling ¹				TGA analysis data				Calcination ²		
		Under Air		Under Argon		Benz. (%)	Under Air		Under Argon		Clay contents (%)	Organic contents (%)
		Water (%)	Acetone (%)	Temp. at d-5%	Temp. at d-10%		Temp. at d-5%	Temp. at d-10%	Chair Yield (%)	Temp. at d-5%		
III _a	00	0.93	0.67	268	286	0.15	—	286	3.21	298	0.00	100.00
III _b	1	0.71	0.62	—	—	Nil	—	294	—	311	0.76	99.24
III _c	5	1.25	0.57	271	290	Nil	271	290	8.40	309	3.80	96.20
III _d	10	1.46	0.5	292	312	Nil	292	312	11.37	315	7.30	92.70
III _e	20	1.68	0.24	268	287	Nil	268	287	13.95	300	13.81	86.19

¹Calculated by adsorbed solvent (g) × 100/dry sample (g).²At 1000°C for 8 hr.

excess solvent was removed by gentle centrifugation. The swelled sample was weighed and re-suspended in the solvent. This procedure was repeated until obtaining on a constant weight for the swelled sample. The swelling degree of each sample is expressed as the amount of sorbed solvent per 100 g of dry sample.

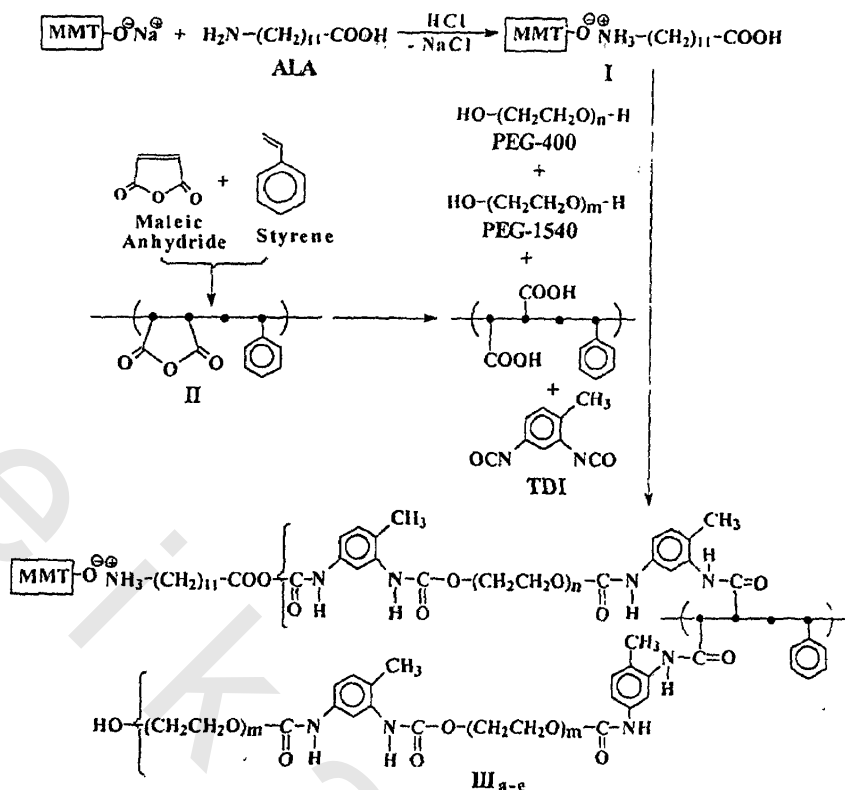
RESULTS AND DISCUSSION

Synthesis and structure

The synthesis of new organic-inorganic nanocomposite materials was achieved by the intercalation of polyurethane onto functionalized montmorillonite clay through *in situ* condensation polymerization technique. The synthesis was carried out through two steps as illustrated in Scheme 1: the first step is the ion exchange process between sodium cation in MMT and ammonium salt of 12-aminododecanoic acid which to organophilic-MMT I. This organophilic-MMT contains carboxylic group to react with diisocyanate and hence promote the interaction of organic materials used in formation of PU and improve the particle-matrix interactions. The calcination indicates the functionalization was achieved with a high degree of conversion (86%). The second step is the solvation of the organoclay with the diols and a solution of preformed poly(styrene-co-maleic anhydride) PSM. This solvation was followed by the addition of the TDI, then casted in films to produce the intercalated polyurethanes III_{a-e} films with different organoclay contents. The structural composition and properties of the product materials was determined by several analytical techniques.

PU-organoclay samples III_{a-e} showed very small swelling in the polar solvents (water and acetone), but they showed no swelling in nonpolar solvents (benzene). The affinity to water shows very small increase with increasing the ratio of clay, which may be attributed to the higher hydrophilic characters of clay. The swelling degree in water (0.7–1.7%), acetone (0.2–0.7%) and benzene (0.0–0.15%) illustrates that there are improvement in the solvent resistance property of the prepared materials.

The IR spectra of the samples were illustrated in Figure 1. The spectra of modified clay I show that the NH stretch band at 3430 cm⁻¹ and NH bend band at 1631 cm⁻¹ are shifted quite substantially to regions associated with ⁻NH₃ vibration which facilitate the ion exchange with MMT. A characteristic band appears at 1040, 522, and 460 cm⁻¹ for Si-O; 2928, 2852 cm⁻¹ for CH aliphatic and at 3608 cm⁻¹ for acidic OH group for I. The quaternary ammonium group (⁻N⁺) shows a characteristic band at 1499 cm⁻¹. The free acidic OH band at 3608 cm⁻¹ in organoclay I is disappeared in nanocomposites indicating the strong interaction is occurred between OH group in organoclay and the isocyanate forming the isocyanate linkage. Comparing the ⁺NH₃ band at 1631 cm⁻¹ in organoclay with nanocomposite it is clear that this band is shifted to higher wavelength at 1721 cm⁻¹ indicating that an interaction occurred between organoclay and the polymer. The spectra of polyurethane III_a shows the absorbance appeared at 1728 cm⁻¹ that was assigned to hydrogen-bonded urethane carbonyl (C=O), 1418 cm⁻¹ to a secondary urethane amide (C-NH). The spectra of the



Scheme 1. Preparation of modified clay I, poly(styrene-co-maleic anhydride) PSM II and PU-modified clay nanocomposites III_{a-e}.

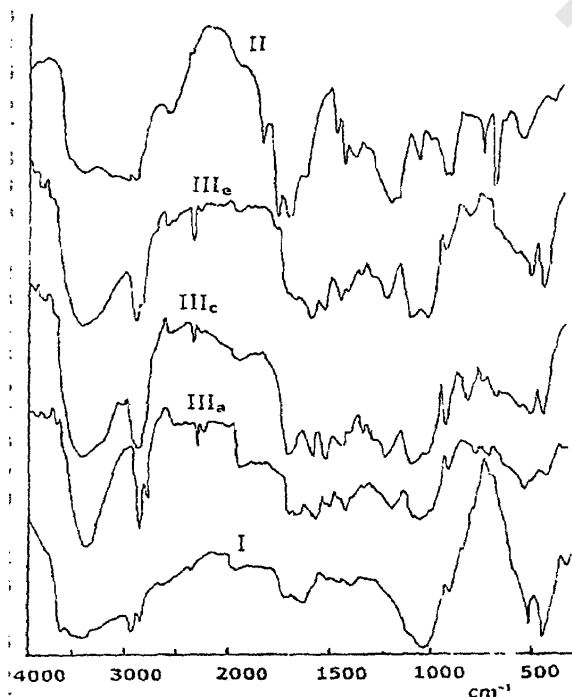


Figure 1. IR spectra for organoclay I, copolymer II and PU-organoclay III_{a,e}.

synthesized PU/modified clay show III_e peaks at 1719 cm^{-1} that caused by the stretching of urethane carbonyl group ($\text{C}=\text{O}$), and 2921 and 2862 cm^{-1} that attributed to the asymmetric and symmetric C-H stretching vibration. The peak at 3425 cm^{-1} resulted from the N-H group in H-bonding. The main features of various bond vibration and H-bonding of these PU-clay nanocomposites are remained near as in the pure PU. These results confirm that there were no major changes in the chemical structural of PU with the dispersion of organoclay in the polymer matrix.

Thermal analysis

Thermal properties of polyurethane-organoclay compounds were determined by TGA under argon atmosphere, in air and calcination. The data are summarized and listed in Table 1. The data TGA show the weight loss encountered during heating the PU-clay materials in the range 86%–97% in air and 91%–78% under argon atmosphere. While, the calcination measurements show that the weight loss ranged from 100% to 86%. It is clearly that the weight loss evident in the calcination measurements is nearly compatible with the TGA data.

The thermograms of the samples III_{a-e} were illustrated Figure 2, which indicate that the thermal decomposition takes place in two stages. The first stage is the sharp and major, which involve the thermal decomposition of the polymers present on the surfaces of the layers of the clay. The

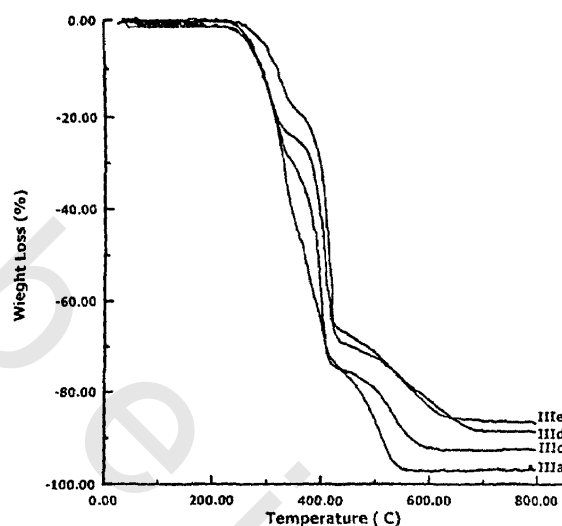


Figure 2. TGA thermograms for the PU-organoclay samples III_{a-e} in air.

decomposition temperature in this stage was started at $\approx 270^\circ\text{C}$ and take place to $\approx 400^\circ\text{C}$, which corresponding the weight loss ranged from $\approx 65\%$ to $\approx 75\%$. In this stage, there is no order can be mentioned between the samples since the difference is small. The second stage is a broad, in which the weight losses ranging from $\approx 20\%$ to $\approx 25\%$ in the temperature range $\approx 400^\circ\text{C}$ to $\approx 650^\circ\text{C}$. In this stage, the samples displayed higher thermal resistance than pure polymers. This stage is attributed to the further decomposition of the rest intercalated polymers present in the interlayer of the clay, or to the losses of OH groups of the clay mineral and the crystallographic structure collapsed or to the losses of some salts in the interlayer of the clay.⁴ The thermal decomposition of samples III_{a-e} under argon atmosphere, Figure 3, is occurred in one step and sharp. The decompo-

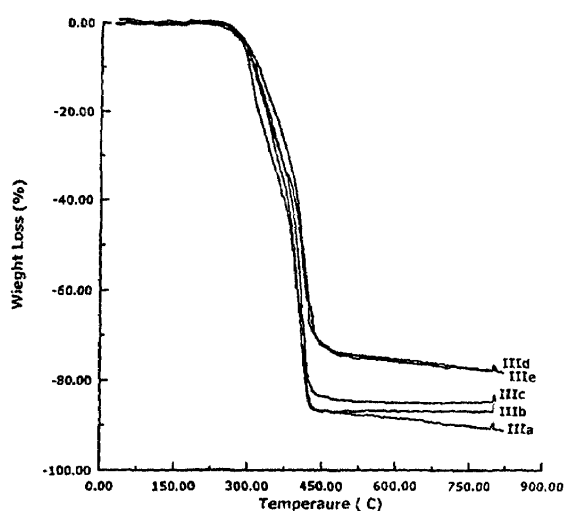


Figure 3. TGA thermograms for the PU-organoclay samples III_{a-e} under argon atmosphere.

sition temperature in this step started from $\approx 290^\circ\text{C}$ to $\approx 425^\circ\text{C}$ due to the thermal decomposition of the polymers present on the surfaces and the intercalated in the layers of the clay. This step followed by a gradually and very smooth and very low weight loss, which may be due to the losses of OH groups of the clay mineral and the crystallographic structure collapsed, or to the further decomposition of some salts in the interlayer of the clay.⁴ The difference in the TGA analysis under argon than in air can be explained for two reasons: (a) the presence of oxygen in air help in the decomposition fast; (b) the higher thermal conductivity in air than in argon leads to the slower decomposition rates under argon than in air as illustrated in Table 1. The temperature at which the samples losses 5% and 10% of its weight is higher under argon than in air for all the samples. These results indicate that the thermal property was improved with increasing the contents of clay in air and under argon

XRD analysis

XRD is powerful technique to observe the extent of silicate dispersion, ordered or disordered structure in the polyurethane nanocomposites. Since, the crystal structure of MMT consists of two-dimensional layers formed by fusing two silica tetrahedral sheets to an edge-shared octahedral sheet of aluminum hydroxide. Stacking of layers of clay particles are held by weak dipolar or Vander Waals forces.³¹ Figure 4 shows typical XRD for the organoclay I and PU-organoclay III_{c-d}. The d_{001} spacing was calculated from peak positions using Bragg's law $d = \lambda / (2 \sin \theta)$. The d -spacing for Na-MMT is increased from $12.34 \text{ \AA}$ ($2\theta = 7.18^\circ$) to $18.24 \text{ \AA}$ ($2\theta = 4.85^\circ$) since the small inorganic Na^+ cation is exchanged by the ammonium group

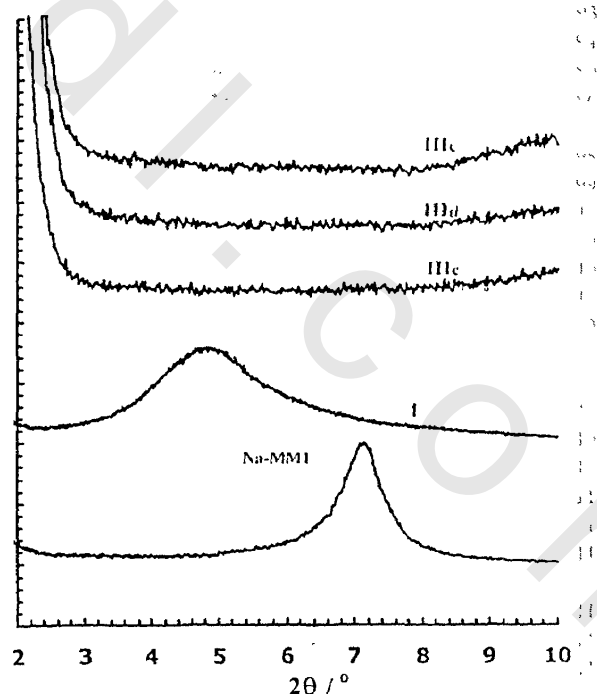


Figure 4. XRD pattern for Na-MMT, organoclay I and PU-organoclay samples III_{c-e}.

of 12-aminododecanoic acid through an ion exchange process. Figure 3, also presents a series of XRD pattern corresponding to polyurethane-clay nanocomposites III_{c,d} with ratios 5%, 10%, and 20% of organoclay I. This figure showed the disappearance of the peak corresponding to intercalated organoclay with all the ratios, which corroborate that the clay was homogeneous dispersion and completely exfoliated in the matrix of polyurethanes. Also, these results confirm that the different percentage of organoclay leads to

high degree of the dispersion in the polymer matrix, as described by another author.³²

SEM examination

The microstructure of the nanocomposites was examined by studying the change in the morphology of the MMT with scanning electron microscope (SEM). The examination of the surface of the deposited samples did not reveal the inorganic domains at the possible magnification. Figures 5a and

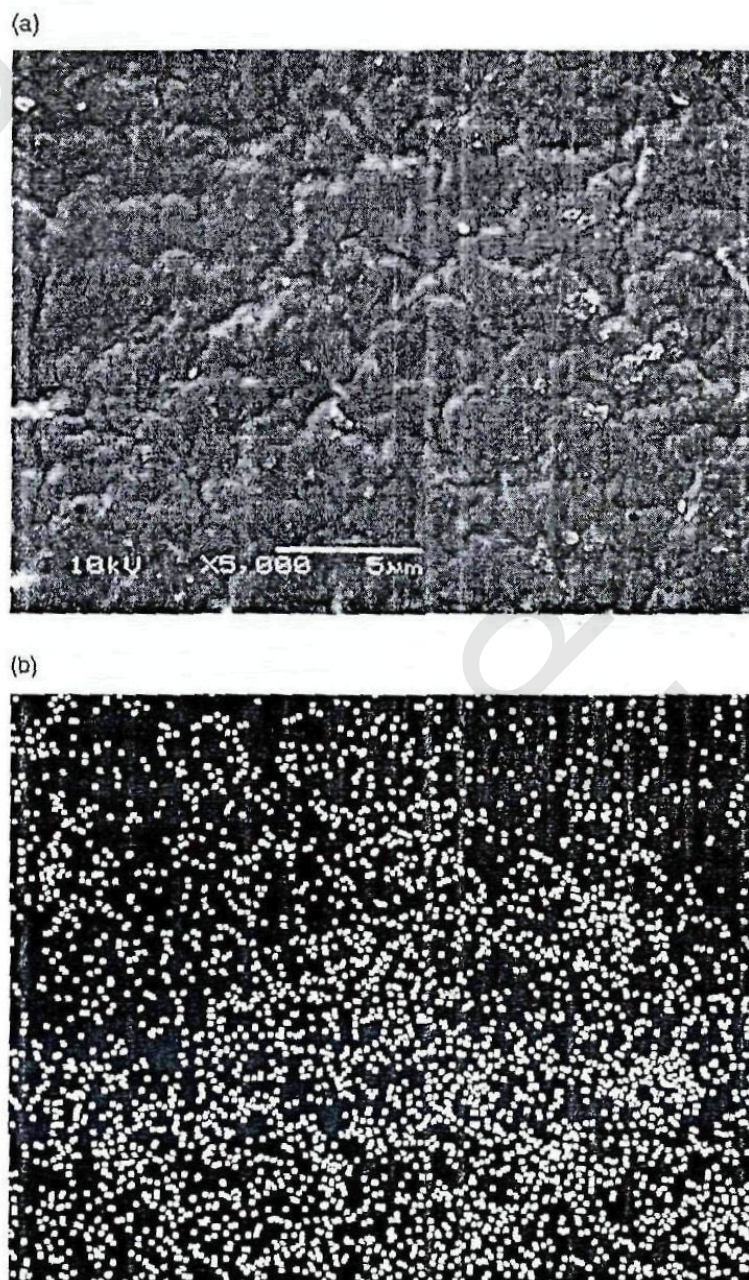


Figure 5. a: SEM image of PU-organoclay sample III_c. b: Elemental mapping for SI of PU-organoclay nanocomposite III_c.

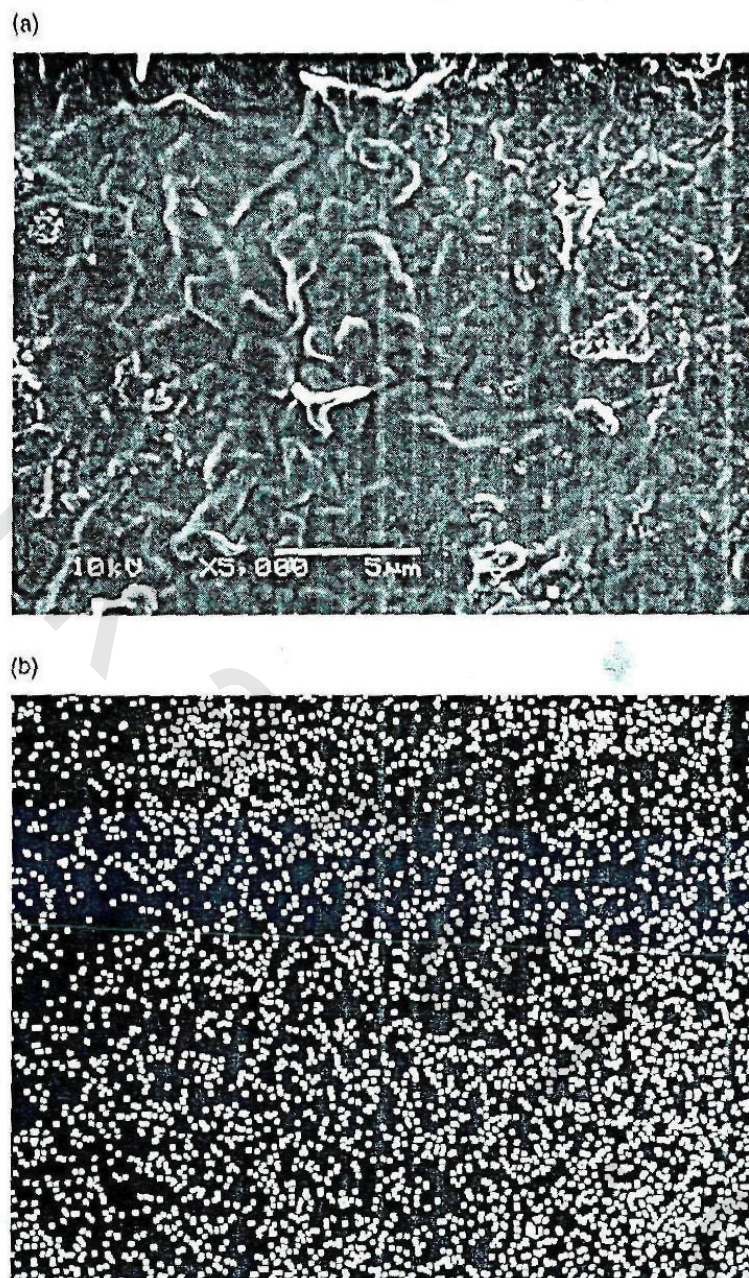


Figure 6. a: SEM image of PU-organoclay sample III_c. b: Elemental mapping for Si of PU-organoclay nanocomposite III_c.

Figure 6a show the micrograph of the samples III_c at 5000 magnifications, which indicates that, the ionic bonding leads to adherence between the polymer and clay, and there is no mineral domains could be seen. This indicates that the agglomerates of mineral domains are broken down to the elementary particles and are homogeneously dispersed in the polymer matrix to produce intercalated and/or exfoliated nanocomposites. Also, the absence of MMT aggregates was confirmed by an energy dispersion x-ray

probe. An image for elemental mapping for Silicon (Si) was shown in Figures 5b and 6b, in which the white dots represent uniformity dispersion of Si element. The Silicon mapping shows that the mineral domains are homogeneously dispersed in the polymer matrix.

The mechanical behavior

The mechanical behavior of PU-organoclay nanocomposites was investigated by measuring the tensile strength and

Table 2. Mechanical properties data for PU-PSM-ALA-MMT nanocomposites films IV_{a-e}

Sample	Organoclay Contents (%)	Film Thickness (μm)	Load cell (M. Pa)		Tensile strength (Kg/cm^2) ^a		Elongation (%)	
			At PK _{max}	At break	At PK _{max}	At break	At PK _{max}	At break
III _a	00	450	3.54	3.42	787	760	311.8	348.0
III _b	1	380	3.67	3.09	966	813	285.6	296.5
III _c	5	360	4.00	2.92	1111	811	180.0	189.0
III _d	10	440	5.38	3.30	1223	750	84.1	90.0
III _e	20	330	4.71	1.99	1427	603	18.2	23.5

^a Calculated from the relation Tensile Strength (Kg/cm^2) = $\frac{\text{Force}}{\text{Area}(w \times t)} = \frac{M \times 10}{\text{cm}^2}$,
Where w is width and t is thickness of the film under test.

elongation at PK_{max} and break as illustrated in Table 2. The data show increasing the tensile strength with increasing the clay contents. Since the tensile strength of III_a, (787 Kg/cm^2 at PK_{max}) was increased to 1111 Kg/cm^2 for III_c with 5% organoclay; and to 1223 Kg/cm^2 for III_d with 10% organoclay; and to 1427 Kg/cm^2 for III_e with 20% organoclay. Figure 7 shows that the tensile strength is highly affected by the contents of the clay, the rate of tensile strength at PK_{max} is largely increased at the small contents (1–5%) of organoclay than at the higher contents. Thus, the tensile strength at break is increased at small quantity of organoclay ($\approx 5\%$) followed by gradual decrease with increasing the organoclay quantities. This may be due to increasing the hardness and the materials start to lose the mechanical properties after the points of PK_{max}.

The data of elongation in Table 2 illustrate decreasing the elongation at PK_{max} and at break with increasing the clay contents, due to increasing the film strength. Figure 8 shows also that the decreasing rate of elongation is higher with small contents (1–5%) than with the high contents of organoclay. These results are similar to the data obtained in the PU-tyramine-clay nanocomposites,²³ which indicate that the tensile strength of PU/SMA/ALA-MMT nanocomposites is higher 6–7 times than the corresponding to PU/Tyr-MMT.

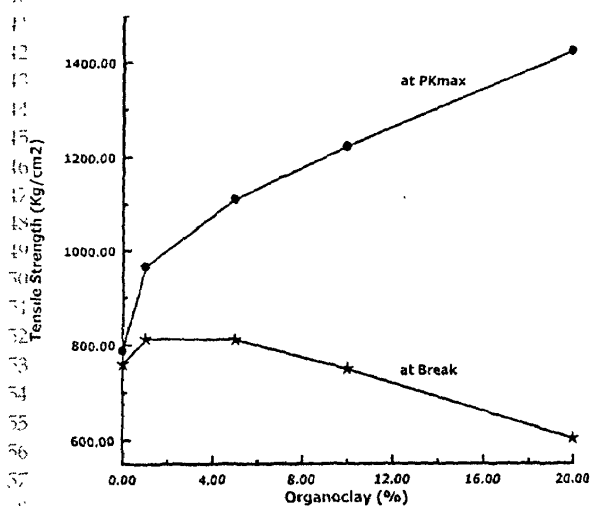


Figure 7. Tensile strength for PU-SMA-ALA-MMT samples.

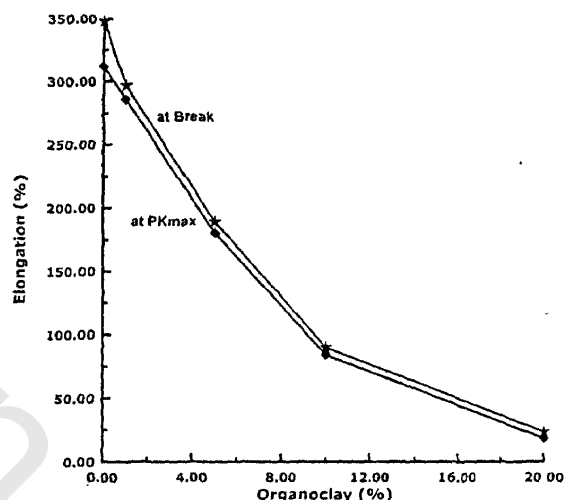


Figure 8. Elongation for PU-SMA-ALA-MMT samples.

CONCLUSIONS

A series of polyurethane-clay nanocomposites were prepared by *in situ* polymerization using different kinds of diols and toluene diisocyanate in the presence of montmorillonite clay modified with 12-aminododecanoic acid. The infrared (IR) spectroscopy confirms the interaction between the polymer and silicate layers. X-ray analysis showed that the d-spacing was increased to exfoliated layers, since there are no peaks corresponding to d_{001} . The morphology of the prepared samples was investigated by SEM, which confirms the dispersion of nanometer silicate layers in the polyurethane matrix. It was found that the presence of organoclay leads to improvement in the mechanical properties, since the tensile strength is increased by the ratio 181% with increasing the organoclay contents to 20%. The elongation was also decreased with increasing the organoclay contents, which is attributed to increasing the stiffness of the film samples. The swelling measurements show that there are improvements in the solvent resistance of the prepared materials. The tensile strength is higher 6–7 times of PU/SMA/ALA-MMT nanocomposites more than the corresponding PU/Tyr-MMT.²¹

REFERENCES

- Andres RP, Datta S, Janes DB, Hubiak CP, Reitenberger R. In *The Handbook of Nanostructured Materials and Technology*, Nalwa HS (ed). Academic Press: Das Deigo, 1998.
- Usuki A, Kawasumi M, Kojima Y, Okada A, Kurauchi T, Kamigaito O. Swelling behavior of montmorillonite cation exchanged for γ -amine acid by 1-caprolactam. *J. Mater. Res.* 1993; 8: 1174–1178.
- Davis RD, Gilman JW, VanderHart DL. Processing degradation of polyamide 6/montmorillonite clay nanocomposites and clay organic modifier. *Polym. Degrad. & Stab.* 2003; 79: 111–121.
- Salahuddin N, Rehab A. New nanocomposites materials based on polymerization of [oligo(oxyethylene) methacrylates] in the presence of montmorillonite clay. *Polym. Int.* 2003; 52: 241–248.
- Salahuddin N, Moet A, Hiltner A, Baer E. Nanoscale highly filled epoxy nanocomposite. *Eur. Polym. J.* 2002; 38: 1477–1482.
- Agag T, Koga T, Takeichi T. Studies on thermal and mechanical properties of polyimide-clay nanocomposites. *Polymer* 2001; 42: 3399–3408.
- Liu X, Wu Q. PP/clay nanocomposites prepared by grafting-melt intercalation. *Polymer* 2001; 42: 10013–10019.
- Wang J, Du J, Zhu J, Wilkie CA. An XPS study of the thermal degradation and flame retardant mechanism of polystyrene-clay nanocomposites. *Polymer Degradation and Stability. Polym. Degrad. & Stab.* 2002; 77: 249–252.
- Oriakhi CO, Zhang X, Lerner MM. Synthesis and luminescence properties of a poly(p-phenylenevinylene)/montmorillonite layered nanocomposite. *Appl. Clay Sci.* 1999; 15: 109–118.
- Chen HW, Chang FC. The novel polymer electrolyte nanocomposite composed of poly(ethylene oxide), lithium triflate and mineral clay. *Polymer* 2001; 42: 9763–9769.
- Lepoittevin B, Devalckenaere M, Pantoustier N, Alexandre M, Kubies D, Calberg C, Jérôme R, Dubois P. Poly(caprolactone)/clay nanocomposites prepared by melt intercalation: mechanical, thermal and rheological properties. *Polymer* 2002; 43: 4017–4023.
- Du J, Zhu J, Wilkie CA, Wang J. An XPS investigation of thermal degradation and charring on PMMA clay nanocomposites. *Polym. Degrad. & Stab.* 2002; 77: 377–381.
- Cho JW, Paul DR. Nylon 6 nanocomposites by melt compounding. *Polymer* 2001; 42: 1083–1094.
- Yano K, Usuki A, Okada A. Synthesis and properties of polyimide-clay hybrid films. *J. Polym. Sci., Part A: Polym. Chem.* 1997; 35: 2289–2294.
- Xie W, Xie RC, Pan WP, Hunter D, Koene B, Tan LS. *Chem. Mater.* 2002; 14: 4837.
- Gilman JW. Flammability and thermal stability studies of polymer-layered silicate (clay) nanocomposites. *Appl. Clay Sci.* 1999; 15: 31–49.
- Kojima Y, Usuki A, Kawasumi M, Okada A, Kurauchi T, Kamigaito O. Sorption of water in nylon 6-clay hybrid. *J. Appl. Polym. Sci.* 1993; 49: 1259–1264.
- Moet A, Akelah A. Polymer-clay nanocomposites: polystyrene grafted onto montmorillonite interlayers. *Mater. Lett.* 1993; 18: 97–102.
- Moet A, Akelah A, Salahuddin N, Hiltner A, Baer E. Layered silicate/ATBN nanocomposite. *Mater. Res. Symp. Proc.* 1994; 351: 163–170.
- Yao KJ, Song M, Hourston DJ, Luo DZ. Polymer/layered clay nanocomposites: 2 polyurethane nanocomposites. *Polymer* 2002; 43: 1017–1020.
- Zilg C, Thomann R, Mülhaupt R, Finter J. Polyurethane nanocomposites containing laminated anisotropic nanoparticles derived from organophilic layered silicates. *Adv. Mater.* 1999; 11: 49–52.
- Rehab A, Salahuddin N. Nanocomposite materials based on polyurethane intercalated into montmorillonite clay. *Mater. Sci. Eng. A* 2005; 399: 368–376.
- Rehab A, Akelah A, Agag T, Shalaby N. Preparation and characterization of polyurethane-organoclay nanocomposites. *Polym. Compos.* 2006; in press.
- Solarski S, Benali S, Rochery M, Devaux E, Alexandre M, Monteverde F, Dubois P. Synthesis of a polyurethane/clay nanocomposite used as coating: Interactions between the counterions of clay and the isocyanate and incidence on the nanocomposite structure. *J. Appl. Polym. Sci.* 2005; 95: 238–244.
- Cao X, Lee LJ, Widya T, Macosko C. Polyurethane/clay nanocomposites foams: Processing, structure and properties. *Polymer* 2005; 46: 775–783.
- Xiong J, Liu Y, Yang X, Wang X. Thermal and mechanical properties of polyurethane/montmorillonite nanocomposites based on a novel reactive modifier. *Polym. Degrad. & Stab.* 2004; 86: 549–555.
- Moon SY, Kim JK, Nah C, Lee YS. Polyurethane/montmorillonite nanocomposites prepared from crystalline polyols, using 1,4-butanediol and organoclay hybrid as chain extenders. *Eur. Polym. J.* 2004; 40: 1615–1621.
- Choi WJ, Kim SH, Kim YJ, Kim SC. Synthesis of chain-extended organo and properties of polyurethane/clay nanocomposites. *Polymer* 2004; 45: 6045–6057.
- Han B, Cheng A, Ji G, Wu S, Shen J. Effect of organophilic montmorillonite on polyurethane/montmorillonite nanocomposites. *J. Appl. Polym. Sci.* 2004; 91: 2536–2542.
- Chen Y, Zhou S, Yang H, Gu G, Wu L. Preparation and characterization of nanocomposite polyurethane. *J. Colloid. Interface Sci.* 2004; 279: 370–378.
- Grim RE. *Clay Mineralogy*, McGraw-Hill: New York, 1968.
- Chen TK, Tien YI, Wei KH. Synthesis and characterization of novel segmented polyurethane/clay nanocomposites. *Polymer* 2000; 41: 1345–1353.

Author Query Form (PAT/887)

Special Instructions: Author please write responses to queries directly on Galley proofs and then fax back.

Q1: Author: Please check the suitability of the suggested short title.

جامعة طنطا
كلية العلوم
قسم الكيمياء

دراسات علي بعض المتراكبات النانومترية المستحدثة للبولى يوريثان مع الطفلة

رسالة

كجزء متمم للحصول على درجة الماجستير فى العلوم
(فى الكيمياء)

مقدمة من

ناصر حلمى صالح شلبى

بكالوريوس علوم- كيمياء

جامعة القاهرة

١٩٨٨

تحت إشراف

الأستاذ الدكتور / أحمد محمد إسماعيل عكيه

الدكتور / أحمد فتح الله رحاب

الدكتور / طارق عبد الرحمن عجاج

٢٠٠٧ م

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

رب أوزعني أن أشكر نعمتك التي أنعمت
عليّ وعلى والديّ
و أن أعمل صالحاً ترضاه وأدخلني برحمتك في عبادك الصالحين
صدق الله العظيم

لجنة الحكم والمناقشة

الاستاذ الدكتور / أحمد محمد عكيه

أستاذ كيمياء البلمرات و رئيس قسم الكيمياء – كلية العلوم
جامعة طنطا

الاستاذ الدكتور /إلهام مصطفى صادق

أستاذ كيمياء البلمرات معهد بحوث البترول

الاستاذ الدكتور / محمد عبد المنعم عوض خطاب

أستاذ الكيمياء الفيزيائية- (بلمرات)- معهد الدراسات العليا و

البحوث-

جامعة الأسكندرية

الدكتور / أحمد فتح الله رحاب

أستاذ مساعد الكيمياء الفيزيائية – كلية العلوم- جامعة طنطا

الملخص العربي

ملخص الرسالة

تحتوى هذه الرسالة على ثلاث اجزاء اساسية هي المقدمة و التجارب العملية و النتائج المناقشة. هذا بالاضافة الى ملخص الرسالة باللغة العربية والانجليزية والاستنتاجات والمراجع التى تم الاستعانة بها فى كتابة الرسالة.

الجزء الأول:

يشتمل على مقدمة عن كيمياء و تركيب واستخدامات البولى يوريثان، ويشتمل أيضا على مكونات وانواع المتراكبات وبعض استخدامات متراكبات البولىمر/طفله النانومترية و على المتراكبات النانومترية للبولى يوريثان/طفلة.

الجزء الثانى:

ويشتمل على وصف تفصيلى لكل من المواد المستخدمة واجهزة القياس التى استخدمت وعلى طريقة التحضير للمتراكبات الوارده فى الرسالة.

الجزء الثالث:

ويشتمل على استعراض ومناقشة النتائج التى تم الحصول عليها. حيث تم التعرف على المواد المحضرة وخواصها التركيبية والحرارية والميكانيكية بالطرق التحليلية المختلفة. وقد أثبتت التحاليل بالأشعة تحت الحمراء تداخل المعدلات السطحية المختلفة والبولىمرات بين طبقات

الطفلة. كما أوضحت دراسة التحليل الحرارى الوزنى أن المتراكبات المحضرة لها ثبات حرارى أعلى من البوليمرات الغير متراكبة مع الطفلة. كذلك أوضحت دراسة خاصة تشرب المذيبات (الانتفاخ) أن المتراكبات المحضرة لها مقاومة واضحة لهذه المذيبات.

أما التركيب البنائى لتلك المتراكبات فقد تم التحقق منه بواسطة الأشعة السينية التى أوضحت أنه قد حدث تفكك كامل لطبقات الطفلة فى البوليمر لتعطى متراكبات نانومترية حيث زادت المسافات البينية بين الطبقات الى أكبر من ٤٤ أنجستروم. كما أوضحت دراسة الشكل الظاهري للمتراكبات بواسطة الميكروسكوب الالىكترونى الماسح أن الطفلة منتشرة بتجانس فى مادة البوليمر، حيث أنه لا تظهر التجمعات الطباقية للطفلة واثبتت ذلك صورة عنصر السيليكون والتى توضح توزيع متجانس لهذا العنصر وهو المكون الأساسى للطفلة. و تبين تفكك كامل لطبقات الطفلة فى حالة احتواء المتراكب على ٣% من الطفلة المعدلة و تفكك جزئى فى حالة احتوائه على ٧% او ١٠%.

هذا وقد تمت دراسة الخواص الميكانيكية والتى أوضحت تحسن لوجود الطفلة المعدلة، حيث زادت قوة الشد بمقدار ١٧٧ - ١٩٤ % للمتراكبات المحتوية على ٢٠% طفلة معدلة مقارنة بالبولي يوريثان الذى لا يحتوي على الطفلة المعدلة. هذا وقد دلت النتائج على زيادة قوة الشد للمتراكبات المحتوية على الطفلة المعدلة بحامض الأمينولويوريك فى وجود البوليمر الثنائى المكون من (ستيرين-ماليك أنهايدريد) بمقدار ٦-٧

مرات عن المتراكبات المحتوية على الطفلة المعدلة بالتيرامين أو المعدلة بمركب داي ميثيل اوكتاديسيل-(٤- فينيل بنزيل) أمونيوم كلوريد.

وأما نسبة الاستطالة فقد وجد أنها قلت مع زيادة نسبة الطفلة المعدلة بالتيرامين أو حامض الأمينولويوريك. أما في حالة الطفلة المعدلة بمركب داي ميثيل اوكتاديسيل-(٤- فينيل بنزيل) أمونيوم كلوريد فقد لوحظ زيادة الاستطالة مع زيادة نسبة الطفلة المعدلة.

الى جانب ما سبق يوجد ملخص للاستنتاجات التي تم التوصل اليها من هذه الدراسة واستعراض للمراجع التي تم الاستعانة بها.