# REFERENCES


1. Richard A. Vaia, Air Force Research Laboratory's Materials and Manufacturing Directorate. ML-02-04 [Online]. (n.p.), Available from : http://www.afrl.af.mil /techconn/index.htm [2005, January 18]

2. Clay types [Online]. (n.p.), Available from : http://www.calearthminerals.com /claytypes.htm [2005, January 4]

3. Nanocor®. Nanoclay Structures [Online]. (n.p.). Available from : http://www.nanocor.com/nanostruct.asp [2005, January 29]

4. D. Merinska, L. Kovarova, A. Kalendova, J. Vaculik, Z. Weiss, M. Chmielova, J. Malac and J. Simonik. Polypropylene nanocomposite based on the montmorillonite modified by octadecylamine and stearic acid co-intercalation, Journal of Polymer Engineering. 23 (2003) : 241-257.

5. J.H Choy, K. Yano, A.Okada. Synthesis and properties of polyimide-clay hybrid Films. Journal of Polymer Science : Part A : Polymer Chemistry. 35 (1997) : 2289-2294

6. J.G. Ryu, S.W. Park, H.Kim, J.W. Lee. Power Ultrasound effects for in situ compatibilization of polymer-clay nanocomposite. Materials Science and Engineering C. 24 (2004) : 285-288

7. Jordan, J.W. Organophilic Bentonites; Swelling in Organic Liquid. Journal of phys Colloid Chem. 53 (1949) : 294-306

8. A. Sánchez-Solís, I. Romero-Iearra, M.R. Estrada, F. CALDERS, and O. Manero. Mechanical and Rheological Studies on Polyethylene Terophthalate-Montmorillonite Nanocomposites. Polymer Engineering and Science. 44(2004) : 1094-1102

9. Y.Q. Zhang, J.H. Lee, H.J. Jang, C.W. Nah. Preparing PP/clay nanocomposites using a swelling agen. Composites Part B : engineering. 35 (2004) : 133-138

10. G. Liang, J. Xu, S. Bao, W. Xu. Polyethylene/Maleic Anhydride Grafted Polyethylene/Organic-Montmorillonite Nanocomposites. I. Preparation, Microstruture, and Mechanical Properties. Journal of Applied polymer Science. 91 (2004) : 3974-3980

11. J.H. Chang, Y.U. An, D. Cho, E.P. Giannelis. Polyclactic acid nanocomposites comparison of their properties with montmorillonite and synthetic mica [II]. Polymer. 44 (2003) : 3715-3720

12. A. Pegoretti, J. Kalarik, C. Peroni, C. Migliaresi. Recycled poly [ethylene terephthalate] / layered silicate nanocomposites : morphology and tensile mechanical properties. Polymer. 45 (2004) : 2751-2759

13. Ajuan Gu, Shiao-Wei Kuo, Feng-Chin Chang. Syntheses and Properties of PI / clay Hybrids. Journal of Applied Polymer Science. 79 (2001) : 1902-1910

14. J.H. Chang, P.S. Seo, D.H. Hwang. An exfoliatation organoclay in thermotropic liquid crystalline polyester nanocomposites. Polymer. 43 (2002) : 2969-2974

15. D.C. Lee, L.W. Jang. Characterization of epoxy-clay hybrid composite prepared by emulsion polymerization. Journal of Applied Polymer Science. 68(1998) : 1997-2005

16. L. lui, Z. Qi, X. Zhu. Studies on Nylon 6/clay nanocomposites by melt-intercalation process. Journal of Applied Polymer Science. 71 (1999) : 1133-1138

17. N. Hasegawa, H. Okamoto, H. Kawasumi, A. Usuki. Preparation and mechanical properties of polystyrene-clay hybrids. Journal of Applied Polymer Science. 74 (1999) : 3359-3364

18. E.P. Giannelis. Polymer layered silicate nanocomposites. Advanced Material. 8(1996) : 29-35

19. P.M. Ajayan, L.S. Schadler, P.V. Braun, Nanocomposite Science and Technology. 1 st ed, Wiley-VCH, (2004)

20. JAMES. M. MARGOLIS, Engineering thermoplastics (properties and applications). New York , Marcel Dekker, (1985)

21. A. Brent Strong, Plastics : Materials and Processing. New Jersey: Prentic-Hall, (1996)

22. K. Yangchuan, L. Chenfen, Zongneng Q. crystallization, properties, and crystal and Nanoscale Morphology of PET-clay Nanocomposites. Journal of Applied polymer science. 71(1999) : 1139-1146

23. J. Brandrup, E.H. Immergut, E.A. Grulke, Polymer Handbook. 4 th e.d.,New York, John Wiley & Sons,(1999)

24. Organic Chemical Process Industry [Online]. (n.p.). Available from : http://www.epa.gov/ttn/chief/ap42/ch06/final/c06s06-2.pdf [2005,January 27]

25. J. Scheirs, T.E. Long, Modern Polyesters : Chemistry and Technology of Polyesters and Copolyesters. New York: John Wiley & Sons, (2003).

26. Polyester [Online]. (n.p.). Available from : http://www.psrc.usm.edu/macrog/pet.htm [2005, January 27]

27. G. Odian, Principles of polymerization. 3 rd ed. Singapore :John Wiley & Sons, (1991).

28. Jyotsna Vedula, "Reorganization of structure to alter the properties of PET", M.S thesis in graduate faculty of North Carolina State University, (2005)

29. Shmuel Yariv, Harold Cross, Organo-Clay Complexes and Intercalations. New York : Marcel Dekker , (2002).

30. Garrison Sposito. Surface geopchemistry of the-clay minerals [Online]. (n.p.). Available from : http://www.pubmedcenter.nih.gor/articlerender.fcqi?artid=34 275p [2005, February 10]

31. Ralph E. Grim, Applied Clay Mineralogy., New York, Mc Graw-Hill, (1962).

32. Prof. Stephen A. Nelson. Clay Mineral [Online]. (n.p.).
Available from : http://www.tulane.edu/~sanelson/geol211/clayminerals.htm
[2005, February 10]

33. Terence H. Cooper & Regents of the University of Minnisota. Clay Minerals [Online]. (n.p.). Available from : http://www.soils.agri.umn.edu/academics/classes/soil 2125/doc/s12chap2.htm [2005, February 4]

34. Montmorillonite Available from : http://www.materialkemi.lth.se/course-projects/HT 2004/KK045/clayminerals/montmorillonite.htm [2005, February 10]

35. University of Minnesota. Clay Minerals and Cation Exchange Capacity. PLSC204 [Online]. (n.p.). Available from: http://www.store.adobe.com/webobjects/WEC?pageID=RegMp1&awe_301001&platformCode=WIN&version=5.0&namecode=ACRO&languageCode=USENGLIS&SystemCode=AOLN [2005, February 24]

36. W.E. Worrall, Clay and ceramic raw materials. 2 nd ed., New York: Elsevier Applied Science, (1986)

37. P. Rusmee. High Strength Composites [Online]. (n.p.).
Available from : http://www.mech.utah.edu/~rusmeeha/labnotes/composite. html
[2005, July 19]

38. Courtesy of SP System. Composite – Basic Introduction [Online]. (n.p.).
Available from : http://www.azom.com/details.asp?ArticleD=962# [2005, July 19]

39. Mel M. Schwartz, Composite Materials: Properties, Nondestructive Testing, and Repair. 1 (1997) : 259.

40. Nanocomposites : Small Particles, Huge Effects [Online]. (n.p.).
Available from: http://www.psrc.usm.edu/macrog/mpm/composit/nano/in dex.htm
[2005, February 22]

41. Martin A. Van Es, "Polymer-Clay Nanocomposite: The importance of particle dimension", polymer Material and Engineering, Delft University of Technology, Delft, The Natherland Available from : http://www.polymer.tudelft.lnl [2005, February 10]

42. Frederick T. Wallenberger, Norman E. Weston, Natural Fibers, Plastics and Composites. New York : Kluwer, (2004)

43. Prof. J.N. Hay, S.J. Shaw. A review of Nanocomposites 2000 : Nanocomposite-Properties and Applications [Online]. (n.p.). Available from : http://www.azom.com/details.asp?ArticleD=921 [2005, July 19]

44. T.J. Pinnavaia, G.W. Beall, Polymer-Clay Nanocomposites. Chichester : John Wiley & Sons, (2000)

45. Laviosa Chimica Mineraria. Synthesis of Nanocomposites [Online]. (Italy). Available from : http://www.laviosa.it/eng/catalogo.asp?Livello=3&catalegoria =RESEARCH/Nanocompositi [2005, February 10]

46. Nanocomposites [Online]. (n.p.). Available from : http://www.cem.msu.edu/~kanatzid/Nanocomposite.html [2005, July 23]

47. L. Ying, Scott Omachinski, Jason Logsdou, J.W. Cho. T.Lan, Technical Paper "Nano-effect in in-situ Nylon-6 nanocomposites". Nanocor, Available from : http:// www.nanocor.com /tech_papers/antec2001.asp [2005, February 10]

48. University of South Carolina Research Foundation. Polymer Nanocomposite Technology Brif [Online]. (n.p.). Available from : http://www.ip.research.sc.edu/PDF/Polymer%20Nanocomposite%20Technology % 20Brief%20v1.pdf [2005, February 10]

49. U.S. Army Research, Development and Engineering Command. Permeation behavior and physical properties of natural rubber nanocomposite [Online].

(n.p.). Available from : http://www.asc2004.com/Manuscripts/sessionM/M0-02.pdf [2005, February 10]

50. Shinkong cooperation, "Technical Specification" Available from : http://www.shinkong.com.tw/shinpet/production/CHIP_E.htm

51. The chemical structure of dioctadecyl dimethyl ammonium chloride Available from: http:// www.azom.com/moterials.asp?Lettler=A#

52. J.H. chang, D.K. park. Nanocomposite of Poly(ethylene terephthalate-co- ethylene naphthalate ) with organoclay. Journal of polymer Science Part B: Polymer Physics. 39(2001) : 2581-2588

53. J.H. Chang, S.J. Kim, Y.L. Joo, S. Im. Poly(ethylene terephthalate) nanocomposites by in situ interlayer polymerization: the thermo-mechanical properties and morphology of the hybrid fibers. Polymer. 45(2004) : 807-813

54. M. Zanetti, G.Camino, R. Thomann, R. Mulhaupt. Synthesis and thermal behaviour of layered silicate-EVA nanocomposites. Polymer. 42(2001) : 4501-4507

55. C. Zhao, H. Qin, F. Ling, M. Feng, S. Zhang, M. yang. Mechanical, thermal and flammability properties of polyethylene/clay nanocomposites. Polymer Degradation and Stability. 87(2005) : 183-189

56. S. Bi, Y. Zhang, H. Bu, Robert R. Luise, Jenny Z. Bu. Thermal Transition of a Wholly Aromaatic Thermotropic Liquid Crystalline Copolyester. Journal of Polymer Science Part A: Polymer Chemistry. 37(1999) : 3763-3769

57. Y. Li, X. Zhu, G. Tian, D. Yan, E.Zhou. multiple melting endotherms in melt-crystallized nylon 10,12. Polymer International. 50(2001) : 677-682

58. Z. Wu, C. Zhou, N. Zhu. The nucleating effect of montmorillonite on crystallization of nylon 1212/montmorillonite nanocomposite. Polymer Testing. 21(2002) : 479-483

# APPENDICES

# APPENDIX A

## INSTRUMENTS

A1. Sample Preparation

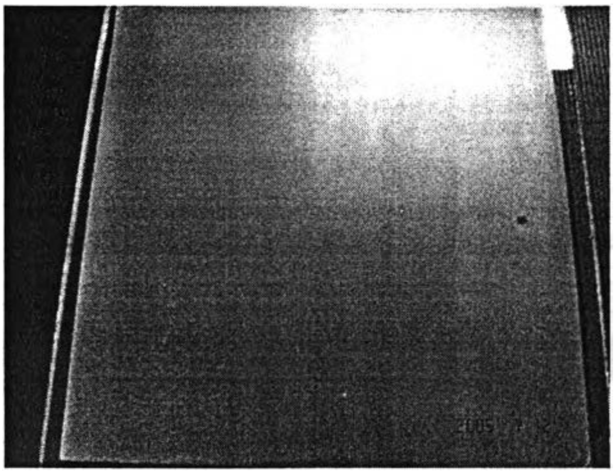


Figure A1.1 Glass mold (glass plate) with film coated

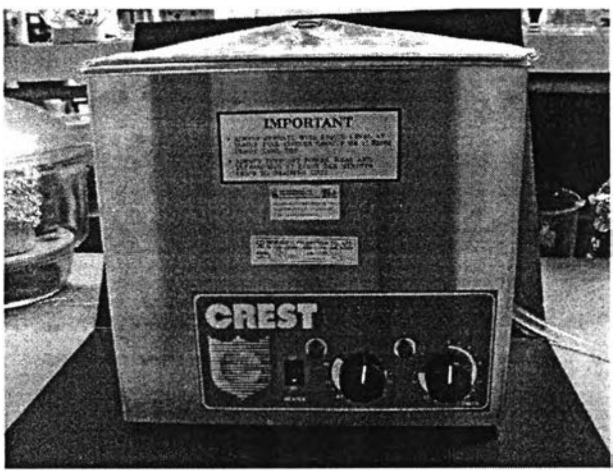



Figure A1.2 Ultrasonic bath, CREST model 575 HT

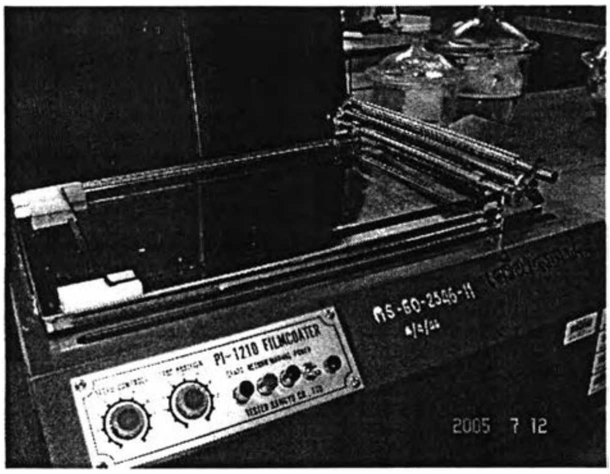



Figure A1.3 Automatic film applicator, model PI-1210 with wire bar coating rod number 75 of Tester Sangyo Co., Ltd

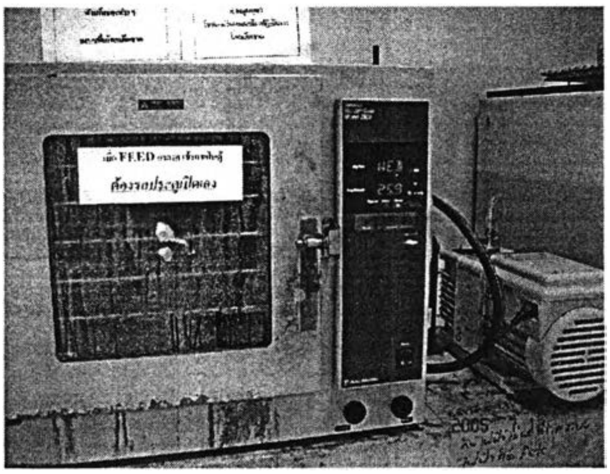


Figure A1.4 Vacuum oven Isotemp®Vacuum oven model 282A, Fisher Scientific

A2. Physical properties

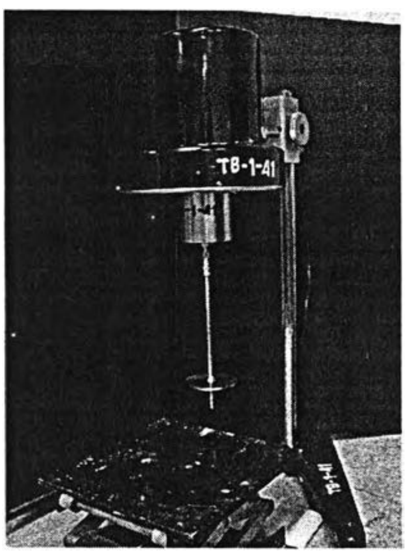



Figure A2.1 The Brookfield viscometer, Peacock, model RVT, with spinner number 2

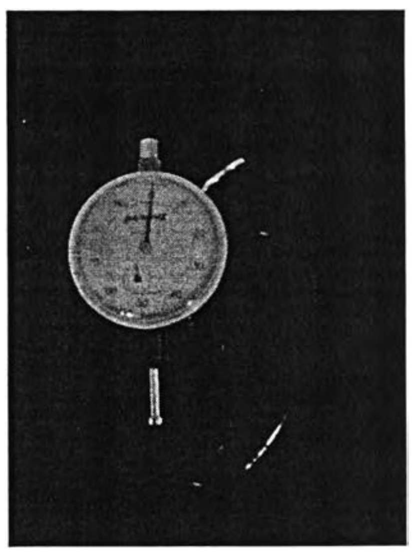


Figure A2.2 A micrometer, Model G, Japan

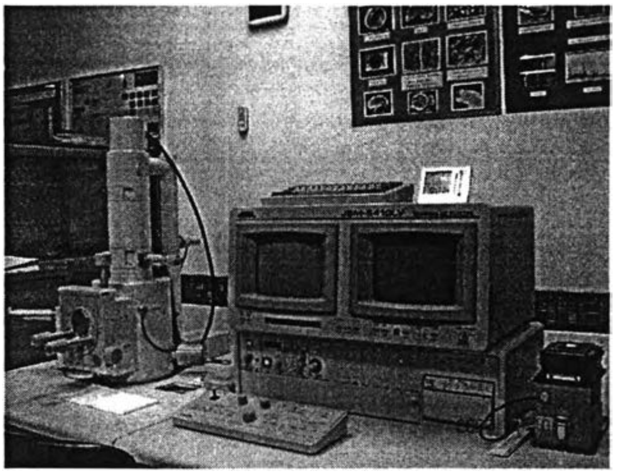


Figure A2.3 Scanning electron microscope, JEOL JSM-5410LV, Japan

Figure A2.4 Macbeth Color-Eye 7000 spectrophotometer, Kollmorgen instruments Corporation

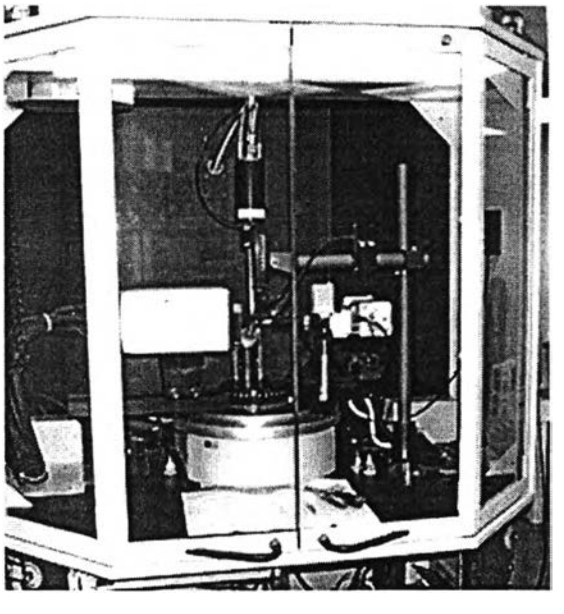


Figure A2.5 Bruker D8 Advance diffractometer

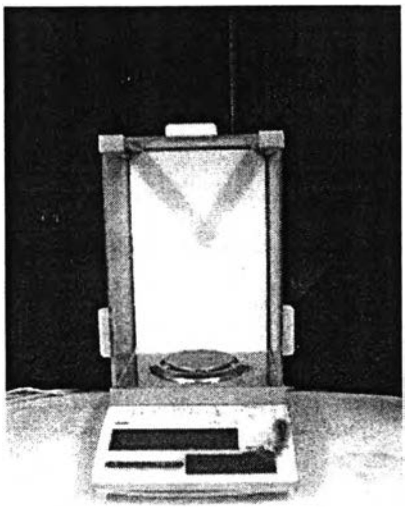


Figure A2.6 An analytical balance, model AB204, Mettler Toledo Ltd.

A3. Mechanical property

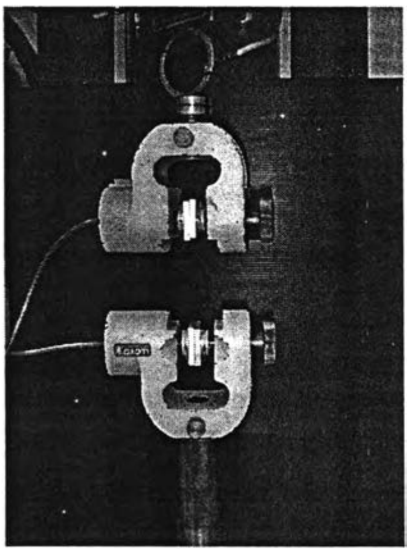


Figure A3.1 Grips of tensile testing machine,
for plastic thin film
LLOYD

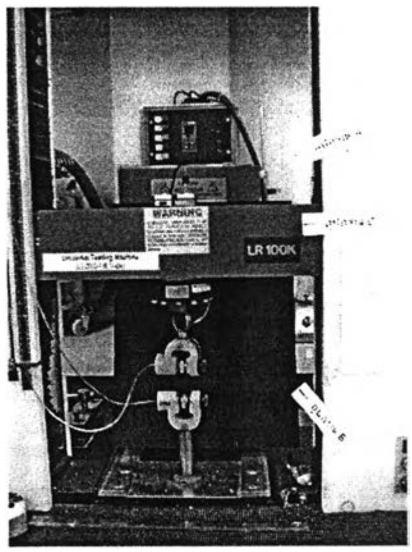



Figure A3.2 Universal testing
model LLOYD LR 100 K,
instruments

A4. Thermal properties

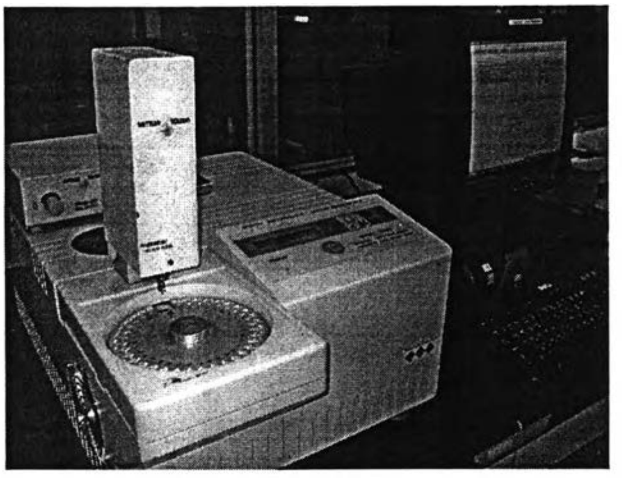


Figure A4.1 Differential Scanning Calorimeter: DSC 822e, Mettler Toledo Ltd.

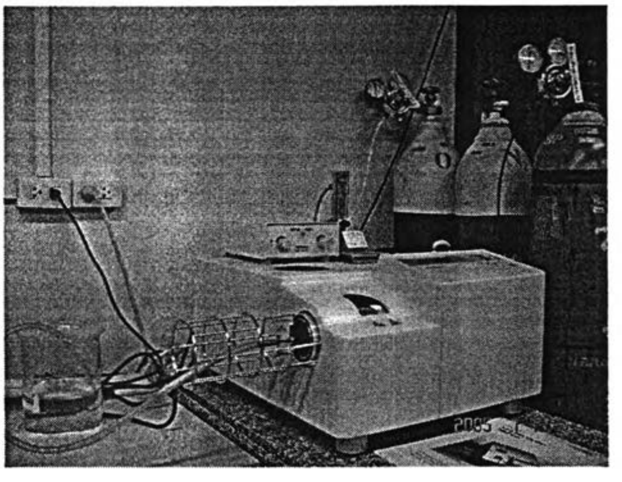


Figure A4.2 Thermogravimetric Analyzer, TGA/SDTA 851[a], Mettler Toledo Ltd.

# APPENDIX B

## PHYSICAL PROPERTIES

### Water absorption

Table B1 The water absorption values (%) at 1 day immersed in water

| Film Sample | | | Condition Weight | | | Wet Weight 1 day | | | Weight increase (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [PET] | Clay type | Clay content (phr) | Trial No. | | | Trial No. | | | Trial No. | | | Mean | SD |
| | | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | | |
| 5 | pure | 0 | 0.0264 | 0.0137 | 0.0156 | 0.0266 | 0.0139 | 0.0159 | 0.7576 | 1.4599 | 1.9231 | 1.3802 | 0.59 |
| | A | 1 | 0.0280 | 0.0447 | 0.0239 | 0.0280 | 0.0454 | 0.0239 | 0.0000 | 1.5660 | 0.0000 | 0.5220 | 0.90 |
| | | 3 | 0.0347 | 0.0154 | 0.0667 | 0.0349 | 0.0154 | 0.0667 | 0.5764 | 0.0000 | 0.0000 | 0.1921 | 0.33 |
| | | 5 | 0.0170 | 0.0673 | 0.0178 | 0.0175 | 0.0673 | 0.0179 | 2.9412 | 0.0000 | 0.5618 | 1.1677 | 1.56 |
| | B | 1 | 0.0420 | 0.0399 | 0.0479 | 0.0422 | 0.0401 | 0.0482 | 0.4762 | 0.5013 | 0.6263 | 0.5346 | 0.08 |
| | | 3 | 0.0310 | 0.0250 | 0.0335 | 0.0313 | 0.0253 | 0.0338 | 0.9677 | 1.2000 | 0.8955 | 1.0211 | 0.16 |
| | | 5 | 0.0508 | 0.0420 | 0.0445 | 0.0513 | 0.0425 | 0.0450 | 0.9843 | 1.1905 | 1.1236 | 1.0994 | 0.11 |
| 7 | pure | 0 | 0.0275 | 0.0345 | 0.0228 | 0.0279 | 0.0347 | 0.0231 | 1.4545 | 0.5797 | 1.3158 | 1.1167 | 0.47 |
| | A | 1 | 0.0288 | 0.0689 | 0.0468 | 0.0289 | 0.0692 | 0.0470 | 0.3472 | 0.4354 | 0.4274 | 0.4033 | 0.05 |
| | | 3 | 0.0567 | 0.0438 | 0.0532 | 0.0568 | 0.0439 | 0.0540 | 0.1764 | 0.2283 | 1.5038 | 0.6361 | 0.75 |
| | | 5 | 0.0350 | 0.0316 | 0.0195 | 0.0354 | 0.0319 | 0.0197 | 1.1429 | 0.9494 | 1.0256 | 1.0393 | 0.10 |
| | B | 1 | 0.0199 | 0.0282 | 0.0206 | 0.0201 | 0.0283 | 0.0207 | 1.0050 | 0.3546 | 0.4854 | 0.6150 | 0.34 |
| | | 3 | 0.0353 | 0.0152 | 0.0293 | 0.0353 | 0.0152 | 0.0295 | 0.0000 | 0.0000 | 0.6826 | 0.2275 | 0.39 |
| | | 5 | 0.0326 | 0.0231 | 0.0334 | 0.0329 | 0.0231 | 0.0336 | 0.9202 | 0.0000 | 0.5988 | 0.5063 | 0.47 |
| 9 | pure | 0 | 0.0256 | 0.0337 | 0.0320 | 0.0259 | 0.0340 | 0.0325 | 1.1719 | 0.8902 | 1.5625 | 1.2082 | 0.34 |
| | A | 1 | 0.0421 | 0.0365 | 0.0355 | 0.0422 | 0.0369 | 0.0357 | 0.2375 | 1.0959 | 0.5634 | 0.6323 | 0.43 |
| | | 3 | 0.0382 | 0.0239 | 0.0413 | 0.0383 | 0.0242 | 0.0413 | 0.2618 | 1.2552 | 0.0000 | 0.5057 | 0.66 |
| | | 5 | 0.0178 | 0.0185 | 0.0246 | 0.0178 | 0.0188 | 0.0248 | 0.0000 | 1.6216 | 0.8130 | 0.8115 | 0.81 |
| | B | 1 | 0.0298 | 0.0290 | 0.0192 | 0.0301 | 0.0292 | 0.0193 | 1.0067 | 0.6897 | 0.5208 | 0.7391 | 0.25 |
| | | 3 | 0.0315 | 0.0334 | 0.0302 | 0.0315 | 0.0334 | 0.0303 | 0.0000 | 0.0000 | 0.3311 | 0.1104 | 0.19 |
| | | 5 | 0.0330 | 0.0349 | 0.0401 | 0.0333 | 0.0352 | 0.0403 | 0.9091 | 0.8596 | 0.4988 | 0.7558 | 0.22 |

Table B2 The water absorption values (%) at 2 day immersed in water

| Film Sample | | | Condition Weight | | | Wet Weight 2 days | | | Weight increase (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [PET] | Clay type | Clay content (phr) | Trial No. 1 | Trial No. 2 | Trial No. 3 | Trial No. 1 | Trial No. 2 | Trial No. 3 | Trial No. 1 | Trial No. 2 | Trial No. 3 | Mean | SD |
| 5 | pure | 0 | 0.0264 | 0.0137 | 0.0156 | 0.0265 | 0.0139 | 0.0159 | 0.3788 | 1.4599 | 1.9231 | 1.2539 | 0.79 |
| | A | 1 | 0.0280 | 0.0447 | 0.0239 | 0.0281 | 0.0453 | 0.0240 | 0.3571 | 1.3423 | 0.4184 | 0.7059 | 0.55 |
| | | 3 | 0.0347 | 0.0154 | 0.0667 | 0.0352 | 0.0154 | 0.0668 | 1.4409 | 0.0000 | 0.1499 | 0.5303 | 0.79 |
| | | 5 | 0.0170 | 0.0673 | 0.0178 | 0.0173 | 0.0674 | 0.0179 | 1.7647 | 0.1486 | 0.5618 | 0.8250 | 0.84 |
| | B | 1 | 0.0420 | 0.0399 | 0.0479 | 0.0424 | 0.0401 | 0.0480 | 0.9524 | 0.5013 | 0.2088 | 0.5541 | 0.37 |
| | | 3 | 0.0310 | 0.0250 | 0.0335 | 0.0313 | 0.0252 | 0.0337 | 0.9677 | 0.8000 | 0.5970 | 0.7883 | 0.19 |
| | | 5 | 0.0508 | 0.0420 | 0.0445 | 0.0514 | 0.0426 | 0.0451 | 1.1811 | 1.4286 | 1.3483 | 1.3193 | 0.13 |
| 7 | pure | 0 | 0.0275 | 0.0345 | 0.0228 | 0.0278 | 0.0348 | 0.0231 | 1.0909 | 0.8696 | 1.3158 | 1.0921 | 0.22 |
| | A | 1 | 0.0288 | 0.0689 | 0.0468 | 0.0289 | 0.0690 | 0.0472 | 0.3472 | 0.1451 | 0.8547 | 0.4490 | 0.37 |
| | | 3 | 0.0567 | 0.0438 | 0.0532 | 0.0572 | 0.0439 | 0.0539 | 0.8818 | 0.2283 | 1.3158 | 0.8086 | 0.55 |
| | | 5 | 0.0350 | 0.0316 | 0.0195 | 0.0353 | 0.0321 | 0.0198 | 0.8571 | 1.5823 | 1.5385 | 1.3260 | 0.41 |
| | B | 1 | 0.0199 | 0.0282 | 0.0206 | 0.0201 | 0.0283 | 0.0207 | 1.0050 | 0.3546 | 0.4854 | 0.6150 | 0.34 |
| | | 3 | 0.0353 | 0.0152 | 0.0293 | 0.0355 | 0.0154 | 0.0294 | 0.5666 | 1.3158 | 0.3413 | 0.7412 | 0.51 |
| | | 5 | 0.0326 | 0.0231 | 0.0334 | 0.0333 | 0.0232 | 0.0337 | 2.1472 | 0.4329 | 0.8982 | 1.1594 | 0.89 |
| 9 | pure | 0 | 0.0256 | 0.0337 | 0.0320 | 0.0258 | 0.0344 | 0.0324 | 0.7812 | 2.0772 | 1.2500 | 1.3695 | 0.66 |
| | A | 1 | 0.0421 | 0.0365 | 0.0355 | 0.0423 | 0.0368 | 0.0357 | 0.4751 | 0.8219 | 0.5634 | 0.6201 | 0.18 |
| | | 3 | 0.0382 | 0.0239 | 0.0413 | 0.0383 | 0.0245 | 0.0415 | 0.2618 | 2.5105 | 0.4843 | 1.0855 | 1.24 |
| | | 5 | 0.0178 | 0.0185 | 0.0246 | 0.0180 | 0.0190 | 0.0249 | 1.1236 | 2.7027 | 1.2195 | 1.6819 | 0.89 |
| | B | 1 | 0.0298 | 0.0290 | 0.0192 | 0.0300 | 0.0292 | 0.0193 | 0.6711 | 0.6897 | 0.5208 | 0.6272 | 0.09 |
| | | 3 | 0.0315 | 0.0334 | 0.0302 | 0.0317 | 0.0337 | 0.0303 | 0.6349 | 0.8982 | 0.3311 | 0.6214 | 0.28 |
| | | 5 | 0.0330 | 0.0349 | 0.0401 | 0.0334 | 0.0352 | 0.0402 | 1.2121 | 0.8596 | 0.2494 | 0.7737 | 0.49 |

Table B3 The water absorption values (%) at 14 day immersed in water

| Film Sample | | | Condition Weight | | | Wet Weight 14 days | | | Weight increase (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [PET] | Clay type | Clay content (phr) | Trial No. 1 | 2 | 3 | Trial No. 1 | 2 | 3 | Trial No. 1 | 2 | 3 | Mean | SD |
| 5 | pure | 0 | 0.0264 | 0.0137 | 0.0156 | 0.0265 | 0.0139 | 0.0159 | 0.3788 | 1.4599 | 1.9231 | 1.2539 | 0.79 |
| | A | 1 | 0.0280 | 0.0447 | 0.0239 | 0.0281 | 0.0454 | 0.0239 | 0.3571 | 1.5660 | 0.0000 | 0.6410 | 0.82 |
| | | 3 | 0.0347 | 0.0154 | 0.0667 | 0.0351 | 0.0154 | 0.0668 | 1.1527 | 0.0000 | 0.1499 | 0.4342 | 0.63 |
| | | 5 | 0.0170 | 0.0673 | 0.0178 | 0.0173 | 0.0674 | 0.0179 | 1.7647 | 0.1486 | 0.5618 | 0.8250 | 0.84 |
| | B | 1 | 0.0420 | 0.0399 | 0.0479 | 0.0424 | 0.0401 | 0.0480 | 0.9524 | 0.5013 | 0.2088 | 0.5541 | 0.37 |
| | | 3 | 0.0310 | 0.0250 | 0.0335 | 0.0312 | 0.0252 | 0.0337 | 0.6452 | 0.8000 | 0.5970 | 0.6807 | 0.11 |
| | | 5 | 0.0508 | 0.0420 | 0.0445 | 0.0514 | 0.0424 | 0.0450 | 1.1811 | 0.9524 | 1.1236 | 1.0857 | 0.12 |
| 7 | pure | 0 | 0.0275 | 0.0345 | 0.0228 | 0.0278 | 0.0348 | 0.0230 | 1.0909 | 0.8696 | 0.8772 | 0.9459 | 0.13 |
| | A | 1 | 0.0288 | 0.0689 | 0.0468 | 0.0288 | 0.0690 | 0.0472 | 0.0000 | 0.1451 | 0.8547 | 0.3333 | 0.46 |
| | | 3 | 0.0567 | 0.0438 | 0.0532 | 0.0570 | 0.0438 | 0.0539 | 0.5291 | 0.0000 | 1.3158 | 0.6150 | 0.66 |
| | | 5 | 0.0350 | 0.0316 | 0.0195 | 0.0354 | 0.0321 | 0.0198 | 1.1429 | 1.5823 | 1.5385 | 1.4212 | 0.24 |
| | B | 1 | 0.0199 | 0.0282 | 0.0206 | 0.0201 | 0.0284 | 0.0207 | 1.0050 | 0.7092 | 0.4854 | 0.7332 | 0.26 |
| | | 3 | 0.0353 | 0.0152 | 0.0293 | 0.0355 | 0.0154 | 0.0295 | 0.5666 | 1.3158 | 0.6826 | 0.8550 | 0.40 |
| | | 5 | 0.0326 | 0.0231 | 0.0334 | 0.0333 | 0.0232 | 0.0336 | 2.1472 | 0.4329 | 0.5988 | 1.0596 | 0.95 |
| 9 | pure | 0 | 0.0256 | 0.0337 | 0.0320 | 0.0258 | 0.0343 | 0.0324 | 0.7812 | 1.7804 | 1.2500 | 1.2706 | 0.50 |
| | A | 1 | 0.0421 | 0.0365 | 0.0355 | 0.0423 | 0.0368 | 0.0357 | 0.4751 | 0.8219 | 0.5634 | 0.6201 | 0.18 |
| | | 3 | 0.0382 | 0.0239 | 0.0413 | 0.0383 | 0.0245 | 0.0415 | 0.2618 | 2.5105 | 0.4843 | 1.0855 | 1.24 |
| | | 5 | 0.0178 | 0.0185 | 0.0246 | 0.0181 | 0.0190 | 0.0249 | 1.6854 | 2.7027 | 1.2195 | 1.8692 | 0.76 |
| | B | 1 | 0.0298 | 0.0290 | 0.0192 | 0.0301 | 0.0291 | 0.0193 | 1.0067 | 0.3448 | 0.5208 | 0.6241 | 0.34 |
| | | 3 | 0.0315 | 0.0334 | 0.0302 | 0.0317 | 0.0338 | 0.0304 | 0.6349 | 1.1976 | 0.6623 | 0.8316 | 0.32 |
| | | 5 | 0.0330 | 0.0349 | 0.0401 | 0.0334 | 0.0352 | 0.0402 | 1.2121 | 0.8596 | 0.2494 | 0.7737 | 0.49 |

# APPENDIX C

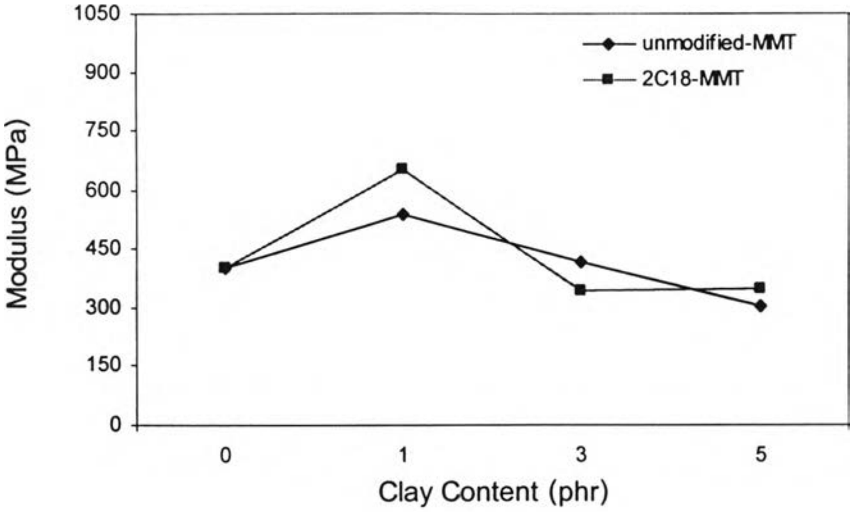
## MECHANICAL PROPERTIES CHARACTERIZATION

Table C1 Tensile modulus (MPa) of PET hybrid films (Machine Direction: MD)

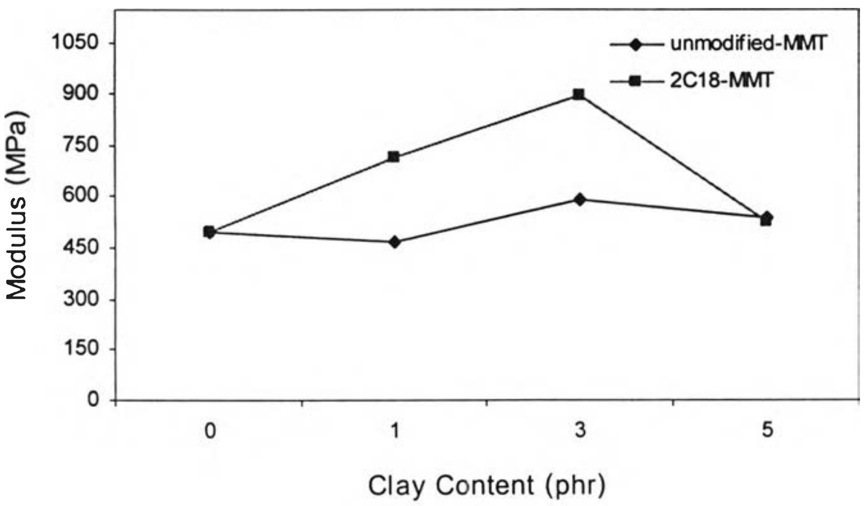
| Formula | Sample Code | Trial No. | | | | | Mean | SD |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| 1 | 5PET-0 | 378.09 | 378.13 | 417.29 | 425.28 | 419.06 | 403.57 | 22.1 |
| 2 | 5PET-A1 | 486.59 | 751.58 | 526.71 | 458.43 | 463.11 | 537.28 | 115.8 |
| 3 | 5PET-A3 | 490.04 | 427.22 | 414.26 | 385.77 | 355.88 | 414.63 | 47.4 |
| 4 | 5PET-A5 | 243.14 | 317.52 | 327.36 | 327.22 | 298.46 | 302.74 | 33.3 |
| 5 | 5PET-B1 | 858.49 | 506.38 | 692.92 | 598.50 | 610.06 | 653.27 | 124.8 |
| 6 | 5PET-B3 | 331.81 | 360.69 | 352.74 | 267.50 | 397.10 | 341.97 | 45.1 |
| 7 | 5PET-B5 | 308.53 | 364.81 | 355.23 | 327.63 | 379.98 | 347.24 | 27.2 |
| 8 | 7PET-0 | 448.40 | 562.91 | 531.82 | 520.31 | 420.09 | 496.71 | 56.5 |
| 9 | 7PET-A1 | 725.30 | 732.53 | 692.74 | 663.25 | 759.88 | 714.74 | 35.3 |
| 10 | 7PET-A3 | 962.73 | 865.22 | 920.78 | 870.32 | 857.72 | 895.35 | 42.5 |
| 11 | 7PET-A5 | 527.98 | 476.04 | 531.25 | 503.23 | 591.51 | 526.00 | 40.4 |
| 12 | 7PET-B1 | 537.82 | 448.97 | 498.77 | 453.78 | 397.84 | 467.44 | 50.1 |
| 13 | 7PET-B3 | 755.74 | 671.37 | 573.74 | 492.34 | 453.03 | 589.24 | 118.0 |
| 14 | 7PET-B5 | 380.87 | 563.65 | 437.95 | 684.58 | 605.75 | 534.56 | 116.8 |
| 15 | 9PET-0 | 547.61 | 552.06 | 620.87 | 613.92 | 544.31 | 575.75 | 36.0 |
| 16 | 9PET-A1 | 588.75 | 679.93 | 632.12 | 572.96 | 553.66 | 605.48 | 47.8 |
| 17 | 9PET-A3 | 467.81 | 614.43 | 426.16 | 358.15 | 367.16 | 446.74 | 97.9 |
| 18 | 9PET-A5 | 453.05 | 497.42 | 516.90 | 489.00 | 434.10 | 478.09 | 31.8 |
| 19 | 9PET-B1 | 654.06 | 569.18 | 642.97 | 564.69 | 528.38 | 591.86 | 51.1 |
| 20 | 9PET-B3 | 802.16 | 877.49 | 861.47 | 850.84 | 806.82 | 839.76 | 31.7 |
| 21 | 9PET-B5 | 534.70 | 518.41 | 580.38 | 559.60 | 589.66 | 556.55 | 28.3 |

Table C2 Tensile modulus (MPa) of PET hybrid films (Transverse Direction: TD)

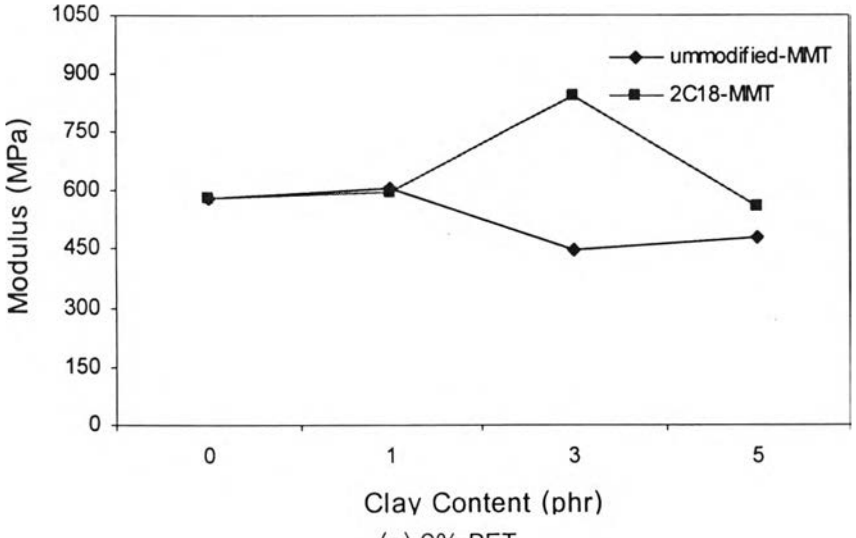
| Formula | Sample Code | Trial No. | | | | | Mean | SD |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| 1 | 5PET-0 | 419.89 | 402.62 | 400.38 | 279.13 | 354.86 | 371.38 | 53.7 |
| 2 | 5PET-A1 | 317.01 | 251.53 | 259.39 | 310.11 | 357.91 | 299.19 | 41.5 |
| 3 | 5PET-A3 | 593.06 | 390.00 | 400.69 | 416.69 | 531.88 | 466.46 | 85.6 |
| 4 | 5PET-A5 | 222.83 | 235.94 | 222.92 | 243.91 | 270.92 | 239.30 | 18.7 |
| 5 | 5PET-B1 | 865.39 | 700.94 | 738.10 | 825.93 | 685.40 | 763.15 | 74.4 |
| 6 | 5PET-B3 | 414.41 | 382.08 | 449.89 | 331.07 | 275.05 | 370.50 | 65.0 |
| 7 | 5PET-B5 | 308.08 | 322.01 | 428.25 | 357.47 | 364.30 | 356.02 | 44.1 |
| 8 | 7PET-0 | 639.48 | 598.57 | 614.17 | 460.63 | 833.64 | 629.30 | 126.0 |
| 9 | 7PET-A1 | 950.04 | 936.35 | 878.64 | 720.12 | 865.44 | 870.12 | 86.1 |
| 10 | 7PET-A3 | 782.72 | 761.54 | 706.02 | 658.54 | 612.88 | 704.34 | 66.5 |
| 11 | 7PET-A5 | 342.94 | 371.69 | 361.73 | 341.11 | 335.87 | 350.67 | 14.4 |
| 12 | 7PET-B1 | 698.74 | 720.49 | 714.28 | 554.70 | 561.47 | 649.94 | 79.4 |
| 13 | 7PET-B3 | 558.14 | 631.03 | 656.09 | 735.17 | 751.53 | 666.39 | 74.6 |
| 14 | 7PET-B5 | 511.51 | 518.79 | 513.12 | 581.31 | 578.96 | 540.74 | 34.0 |
| 15 | 9PET-0 | 517.05 | 569.51 | 577.29 | 552.04 | 581.11 | 559.40 | 24.7 |
| 16 | 9PET-A1 | 762.50 | 671.47 | 759.58 | 820.21 | 717.03 | 746.16 | 52.4 |
| 17 | 9PET-A3 | 462.57 | 465.92 | 504.27 | 516.68 | 481.65 | 486.22 | 22.3 |
| 18 | 9PET-A5 | 757.59 | 727.70 | 864.51 | 756.89 | 766.90 | 774.72 | 49.3 |
| 19 | 9PET-B1 | 598.68 | 569.75 | 625.18 | 644.76 | 654.22 | 618.52 | 32.6 |
| 20 | 9PET-B3 | 1056.40 | 1053.70 | 1017.60 | 898.93 | 994.40 | 1,004.21 | 60.6 |
| 21 | 9PET-B5 | 648.97 | 662.95 | 616.01 | 613.85 | 556.52 | 619.66 | 38.8 |




(a) 5% PET

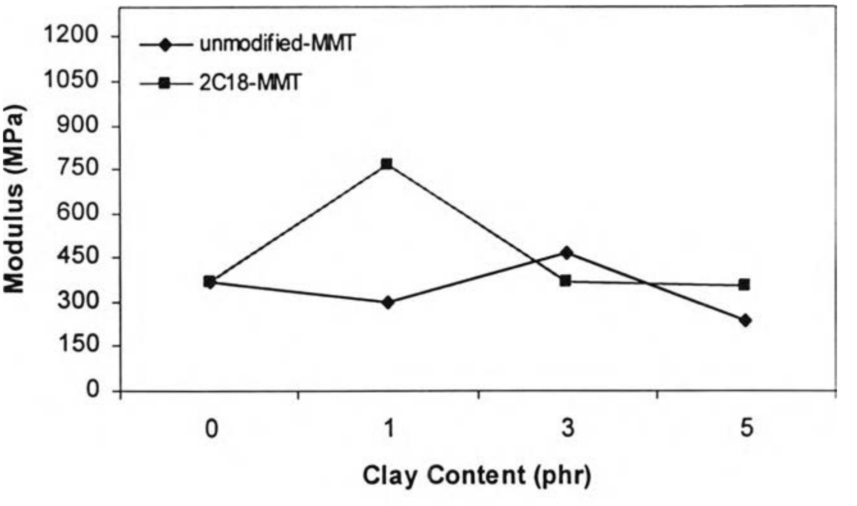



(b) 7% PET

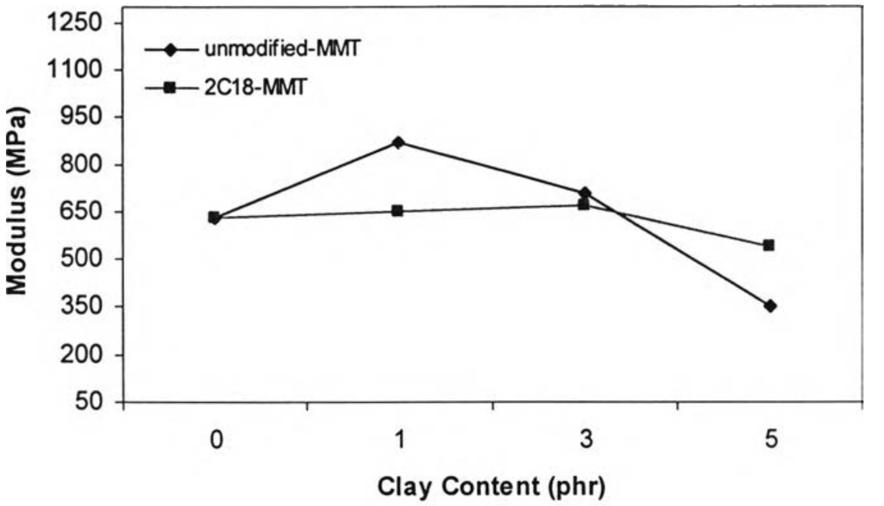



(c) 9% PET

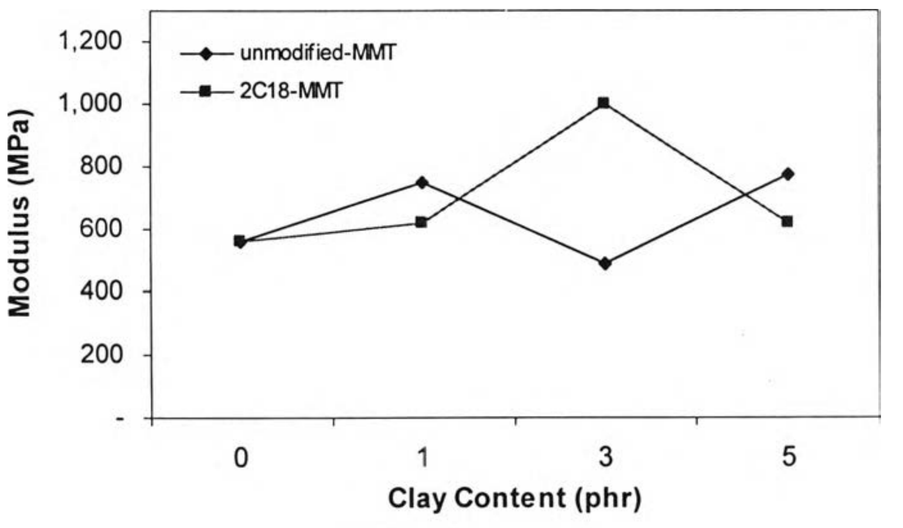
Figure C1 Effect of clay content on the initial tensile modulus of the hybrid films at various PET concentrations (a) 5%, (b) 7%, (c) 9% in machine direction




(a) 5% PET




(b) 7% PET




(c) 9% PET

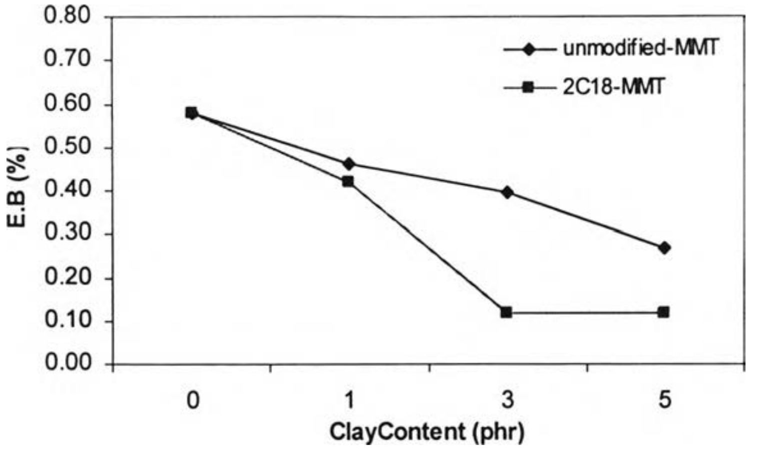
Figure C2 Effect of clay content on the initial tensile modulus of the hybrid films at various PET concentrations (a) 5%, (b) 7%, (c) 9% in transverse direction

Table C3 Percent elongation at break (%) of PET hybrid film (MD)

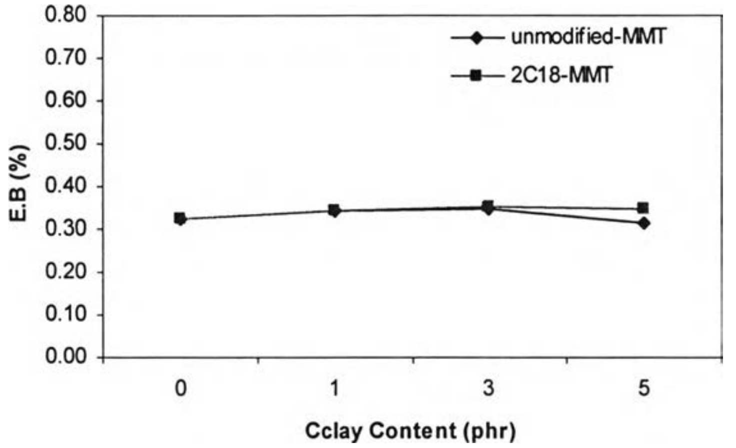
| Formula | Sample Code | Trial No. | | | | | Mean | SD |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| 1 | 5PET-0 | 0.6466 | 0.5307 | 0.6587 | 0.5259 | 0.5401 | 0.5804 | 0.07 |
| 2 | 5PET-A1 | 0.3144 | 0.3955 | 0.6744 | 0.7480 | 0.1643 | 0.4593 | 0.25 |
| 3 | 5PET-A3 | 0.3493 | 0.5325 | 0.3533 | 0.3958 | 0.3403 | 0.3942 | 0.08 |
| 4 | 5PET-A5 | 0.2645 | 0.4101 | 0.2622 | 0.2535 | 0.1447 | 0.2670 | 0.09 |
| 5 | 5PET-B1 | 0.4125 | 0.4032 | 0.4583 | 0.3911 | 0.4296 | 0.4189 | 0.03 |
| 6 | 5PET-B3 | 0.2469 | 0.1553 | 0.0116 | 0.1416 | 0.0247 | 0.1160 | 0.10 |
| 7 | 5PET-B5 | 0.0488 | 0.1605 | 0.1736 | 0.0938 | 0.1197 | 0.1193 | 0.05 |
| 8 | 7PET-0 | 0.2526 | 0.3422 | 0.3227 | 0.3659 | 0.3252 | 0.3217 | 0.04 |
| 9 | 7PET-A1 | 0.4820 | 0.2526 | 0.3794 | 0.2829 | 0.3081 | 0.3410 | 0.09 |
| 10 | 7PET-A3 | 0.4622 | 0.2653 | 0.2645 | 0.3264 | 0.4162 | 0.3469 | 0.09 |
| 11 | 7PET-A5 | 0.1886 | 0.2039 | 0.4437 | 0.2168 | 0.5292 | 0.3164 | 0.16 |
| 12 | 7PET-B1 | 0.4249 | 0.2937 | 0.2978 | 0.3650 | 0.3427 | 0.3448 | 0.05 |
| 13 | 7PET-B3 | 0.5178 | 0.4573 | 0.2135 | 0.2505 | 0.3343 | 0.3547 | 0.13 |
| 14 | 7PET-B5 | 0.2864 | 0.3604 | 0.3867 | 0.3055 | 0.3878 | 0.3453 | 0.05 |
| 15 | 9PET-0 | 0.6721 | 0.7676 | 0.7771 | 0.5182 | 0.5127 | 0.6495 | 0.13 |
| 16 | 9PET-A1 | 0.6865 | 0.6435 | 0.6052 | 0.6478 | 0.4900 | 0.6146 | 0.08 |
| 17 | 9PET-A3 | 0.3585 | 0.6721 | 0.5477 | 0.3038 | 0.4843 | 0.4733 | 0.15 |
| 18 | 9PET-A5 | 0.2877 | 0.3711 | 0.3462 | 0.3255 | 0.2659 | 0.3193 | 0.04 |
| 19 | 9PET-B1 | 0.4055 | 0.4901 | 0.3356 | 0.3680 | 0.5256 | 0.4249 | 0.08 |
| 20 | 9PET-B3 | 0.6745 | 0.5750 | 0.3626 | 0.4685 | 0.4860 | 0.5133 | 0.12 |
| 21 | 9PET-B5 | 0.4497 | 0.3234 | 0.3271 | 0.4071 | 0.5515 | 0.4117 | 0.09 |

Table C4 Percent elongation at break (%) of PET hybrid film (TD)

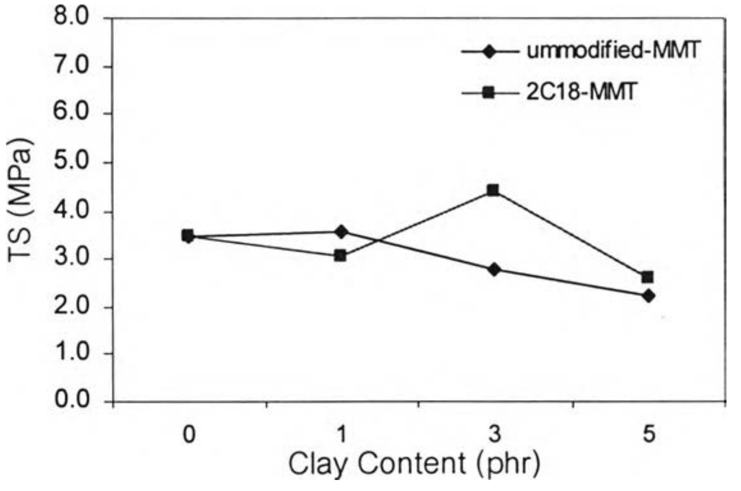
| Formula | Sample Code | Trial No. | | | | | Mean | SD |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| 1 | 5PET-0 | 0.5623 | 0.2788 | 0.3139 | 0.6770 | 0.7684 | 0.5201 | 0.22 |
| 2 | 5PET-A1 | 0.6062 | 0.6200 | 0.8220 | 0.8368 | 0.6435 | 0.7057 | 0.11 |
| 3 | 5PET-A3 | 0.4445 | 0.2987 | 0.3441 | 0.4015 | 0.5490 | 0.4075 | 0.10 |
| 4 | 5PET-A5 | 0.2896 | 0.0972 | 0.0072 | 0.0793 | 0.2767 | 0.1500 | 0.13 |
| 5 | 5PET-B1 | 0.4068 | 0.4117 | 0.2813 | 0.4663 | 0.3859 | 0.3904 | 0.07 |
| 6 | 5PET-B3 | 0.4965 | 0.2243 | 0.2682 | 0.2778 | 0.2050 | 0.2944 | 0.12 |
| 7 | 5PET-B5 | 0.2729 | 0.1614 | 0.2203 | 0.2729 | 0.2201 | 0.2295 | 0.05 |
| 8 | 7PET-0 | 0.5963 | 0.5996 | 0.5695 | 0.6948 | 0.5415 | 0.6003 | 0.06 |
| 9 | 7PET-A1 | 0.4043 | 0.3176 | 0.4052 | 0.5042 | 0.3372 | 0.3937 | 0.07 |
| 10 | 7PET-A3 | 0.4554 | 0.2673 | 0.1231 | 0.4816 | 0.4177 | 0.3490 | 0.15 |
| 11 | 7PET-A5 | 0.2394 | 0.2746 | 0.2207 | 0.3399 | 0.3207 | 0.2791 | 0.05 |
| 12 | 7PET-B1 | 0.4508 | 0.3898 | 0.3708 | 0.3759 | 0.4290 | 0.4033 | 0.04 |
| 13 | 7PET-B3 | 0.4172 | 0.3300 | 0.3443 | 0.3574 | 0.4112 | 0.3720 | 0.04 |
| 14 | 7PET-B5 | 0.3124 | 0.2988 | 0.3551 | 0.3540 | 0.3942 | 0.3429 | 0.04 |
| 15 | 9PET-0 | 0.5898 | 0.7300 | 0.4078 | 0.6129 | 0.7546 | 0.6190 | 0.14 |
| 16 | 9PET-A1 | 0.6258 | 0.5265 | 0.5412 | 0.5775 | 0.6236 | 0.5789 | 0.05 |
| 17 | 9PET-A3 | 0.4385 | 0.2778 | 0.3326 | 0.3865 | 0.4426 | 0.3756 | 0.07 |
| 18 | 9PET-A5 | 0.2323 | 0.2523 | 0.1858 | 0.1823 | 0.1782 | 0.2062 | 0.03 |
| 19 | 9PET-B1 | 0.5766 | 0.4055 | 0.4965 | 0.4570 | 0.5714 | 0.5014 | 0.07 |
| 20 | 9PET-B3 | 0.5016 | 0.5683 | 0.6174 | 0.5035 | 0.6196 | 0.5621 | 0.06 |
| 21 | 9PET-B5 | 0.4703 | 0.4773 | 0.4900 | 0.4740 | 0.5488 | 0.4921 | 0.03 |




(a) 5% PET hybrids

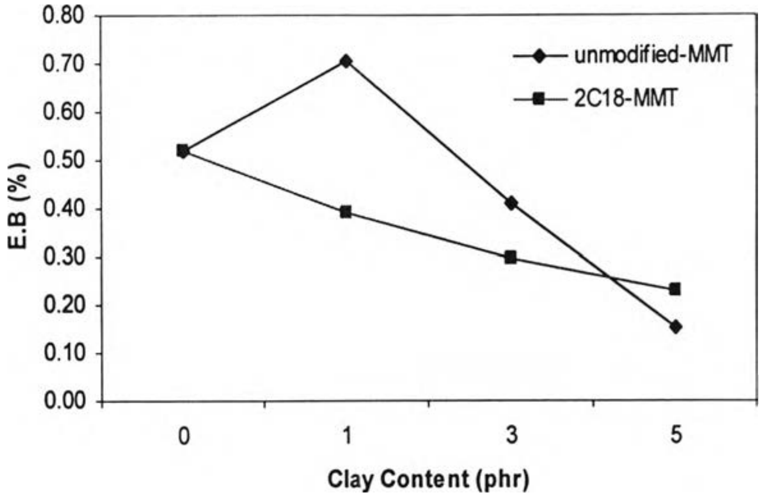



(b) 7% PET hybrids

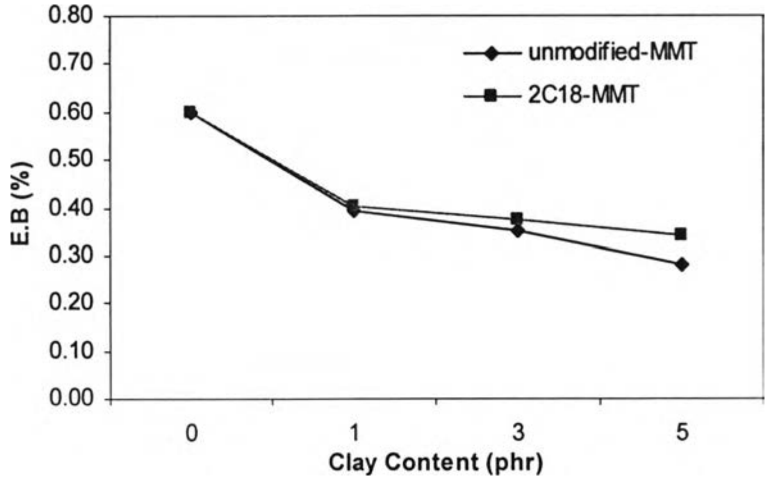



(c) 9% PET hybrids

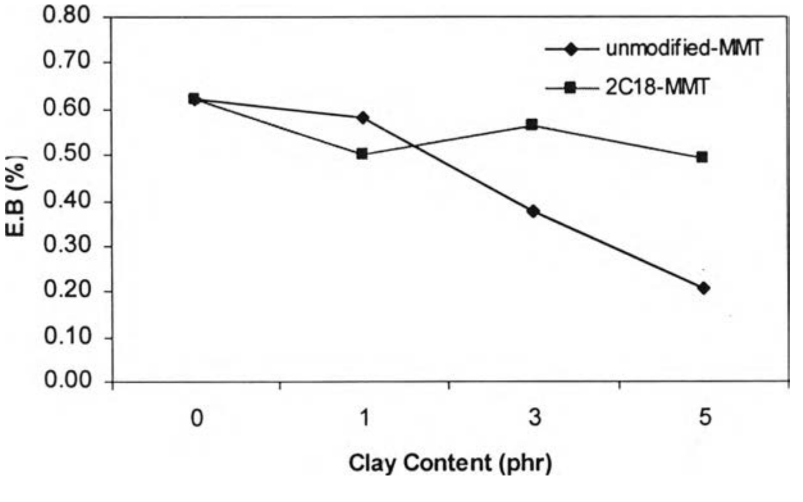
Figure C3 Effect of clay content on the elongation at break of the hybrid films at various PET concentrations (a) 5%, (b) 7%, (c) 9% in MD




(a) 5% PET hybrids

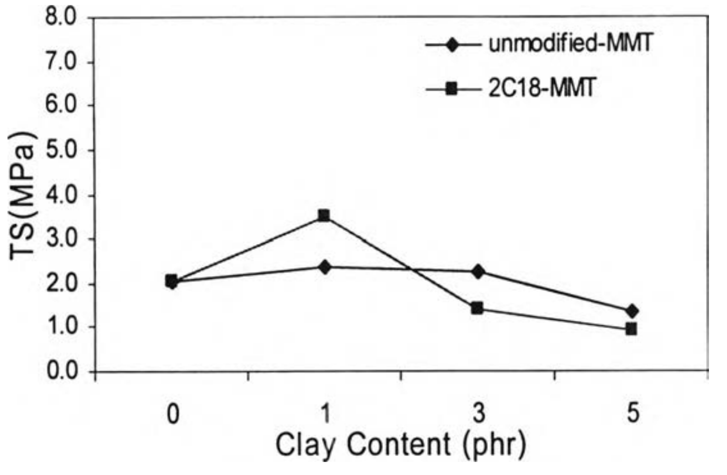



(b) 7% PET hybrids

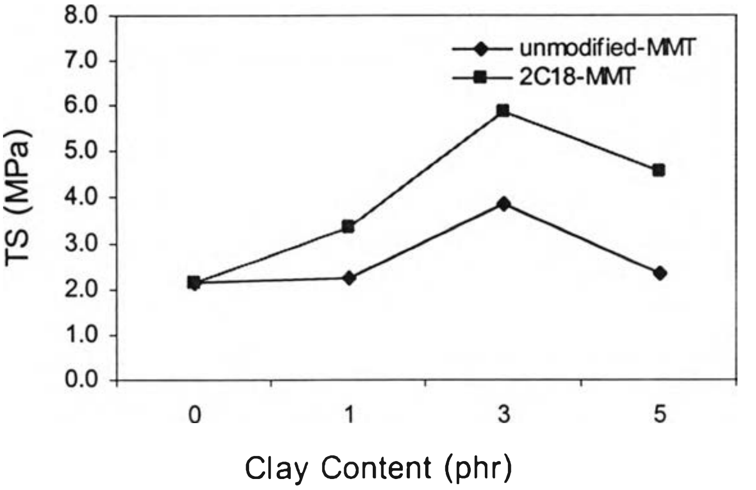



(c) 9% PET hybrids

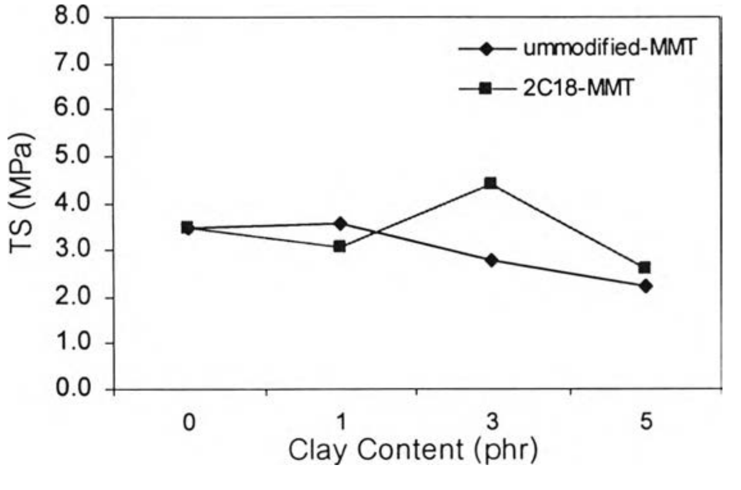
Figure C4 Effect of clay content on the elongation at break of the hybrid films at various PET concentrations (a) 5%, (b) 7%, (c) 9% in TD




(a) 5% PET hybrids

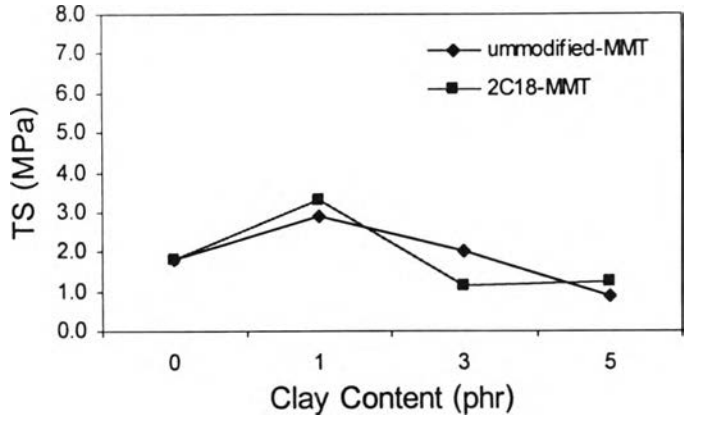



(b) 7% PET hybrids

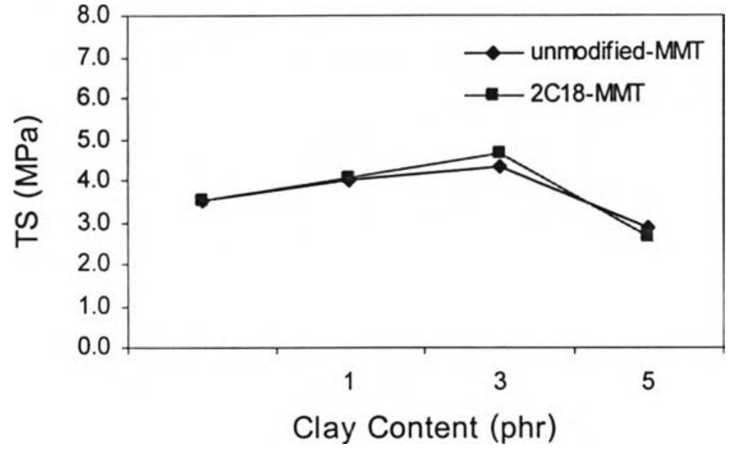



(c) 9% PET hybrids

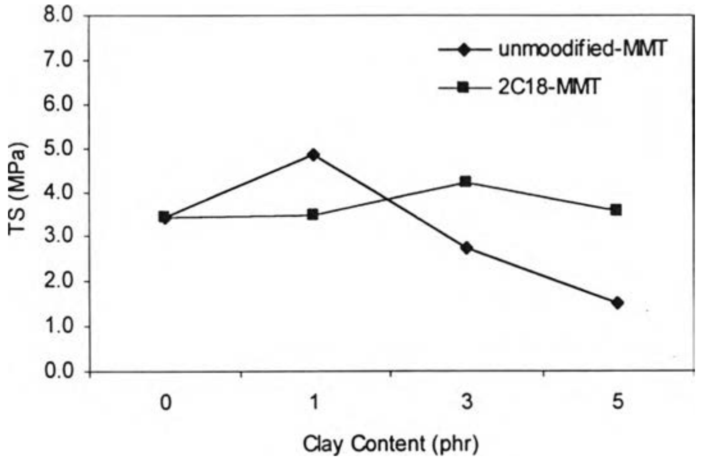
Figure C5 Effect of clay content on the tensile strength of the hybrid films at various PET concentrations (a) 5%, (b) 7%, (c) 9%in machine direction MD




(a) 5% PET hybrids

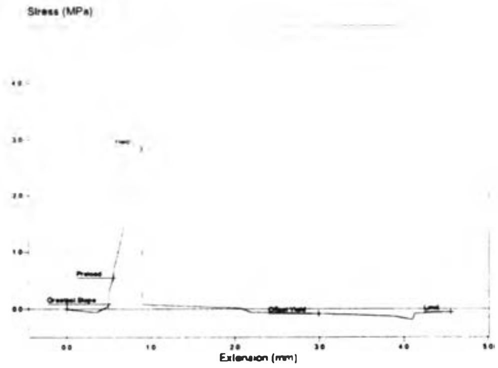



(b) 7% PET hybrids

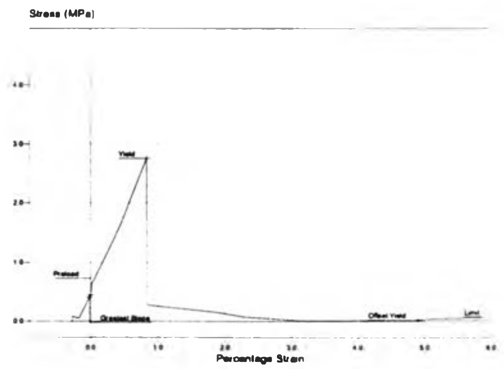



(c) 9% PET hybrids

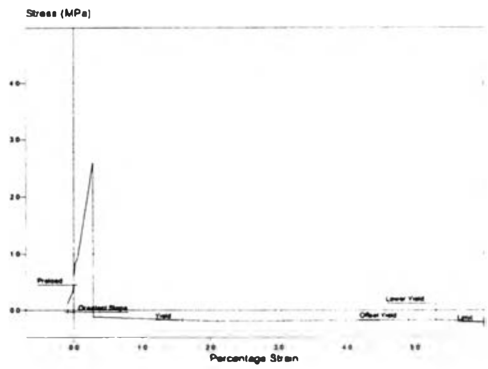
Figure C6 Effect of clay content on the tensile strength of the hybrid films at various PET concentrations (a) 5%, (b) 7%, (c) 9% in transverse direction TD



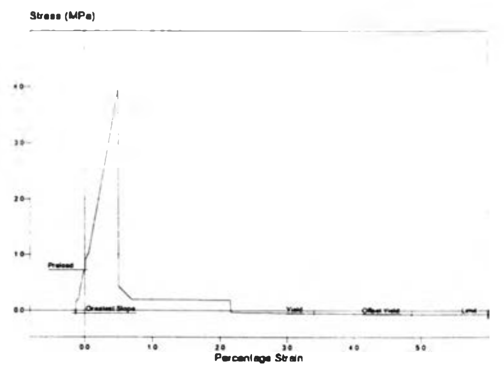

a) Pure 5% PET films



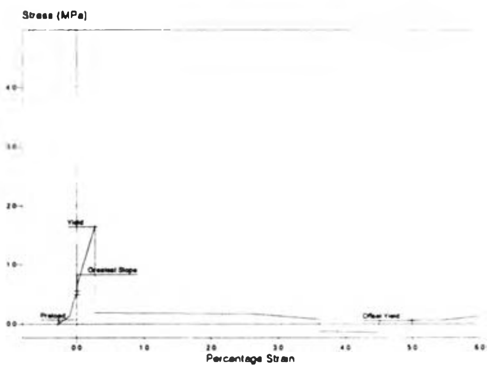

(b) 1 phr MMT



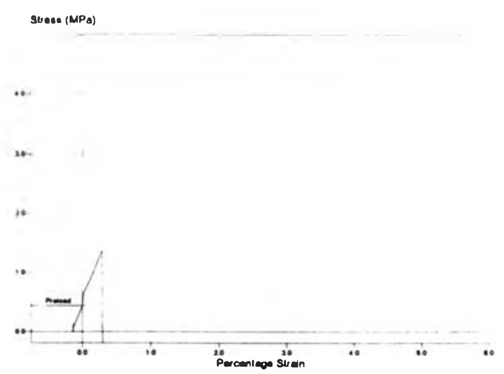

(e) 1 phr 2C18-MMT



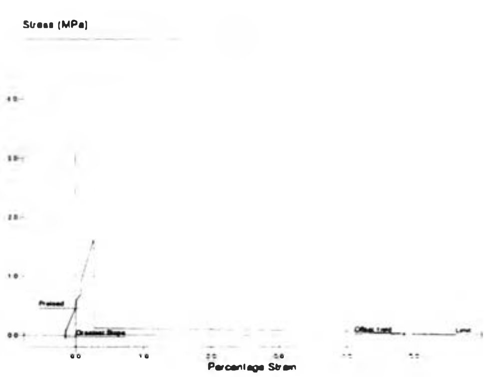

(c) 3 phr MMT




(f) 3 phr 2C18-MMT

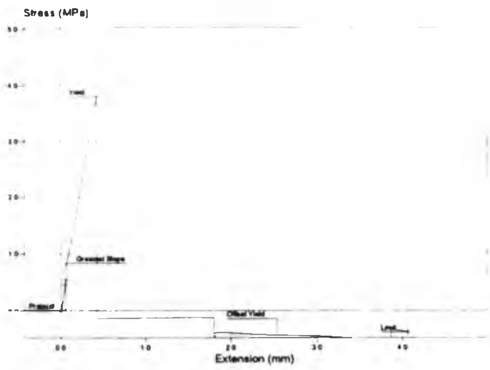



(d) 5 phr MMT

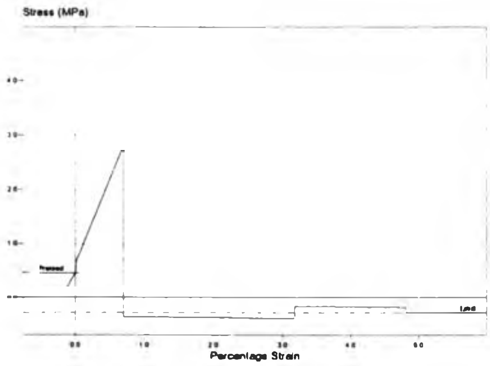



(g) 5 phr 2C18-MMT

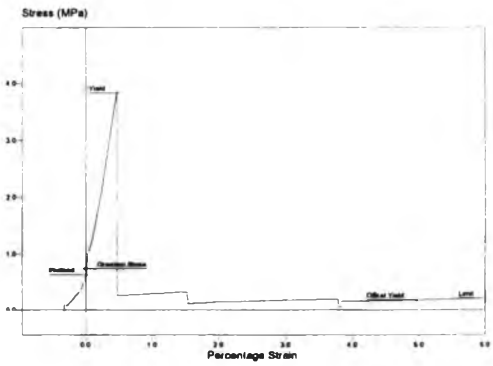
Figure C7 Effect of clay contents on tensile properties of PET/MMT hybrid films at 5% PET concentration in transverse direction (TD)



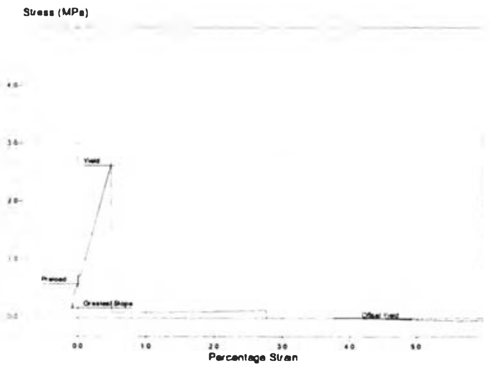

(a) Pure 5% PET films



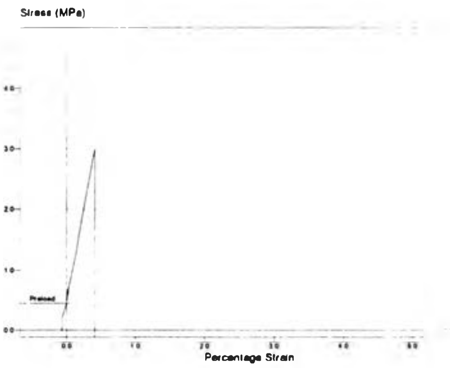

(b) 1 phr MMT



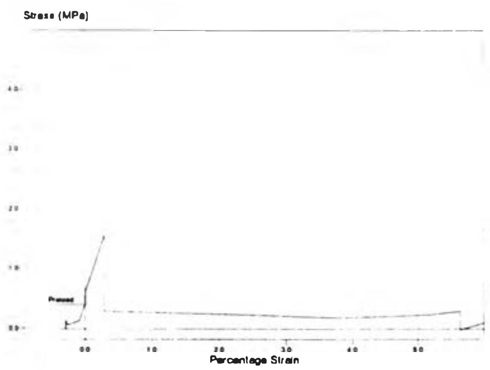

(e) 1 phr 2C18-MMT



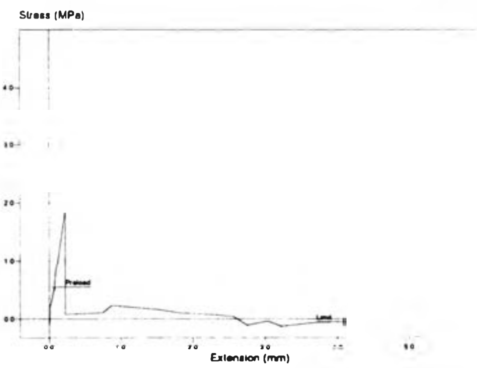

(c) 3 phr MMT




(f) 3 phr 2C18-MMT

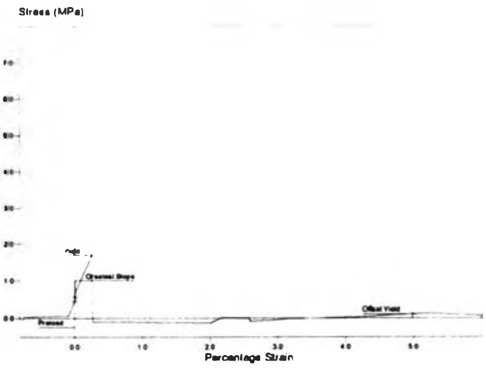



(d) 5 phr MMT

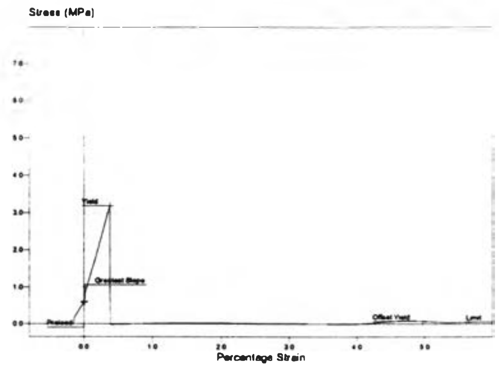



(g) 5 phr 2C18-MMT

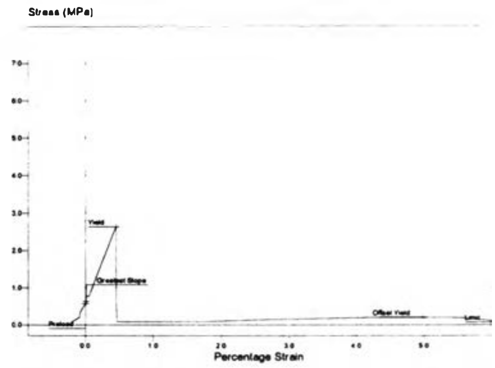
Figure C8 Effect of clay contents on tensile properties of PET/MMT hybrid films at 5% PET concentration in machine direction (MD)



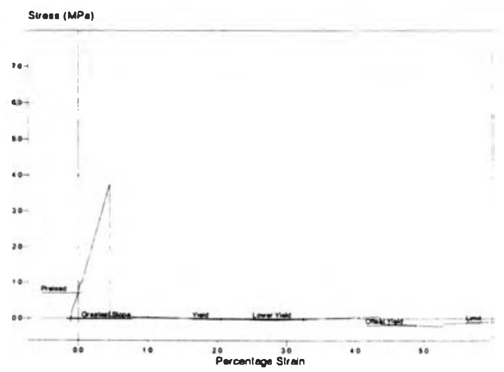

(a) Pure 7% PET films



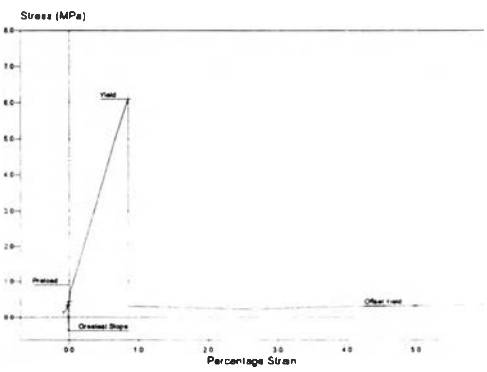

(b) 1 phr MMT



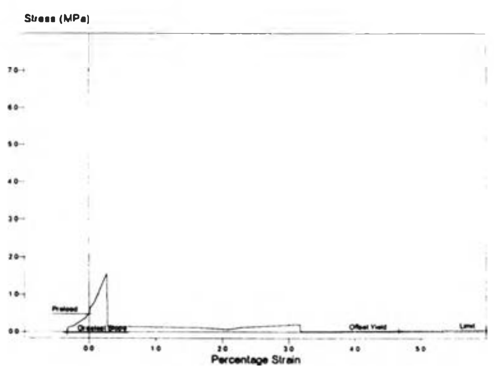

(e) 1 phr 2C18-MMT



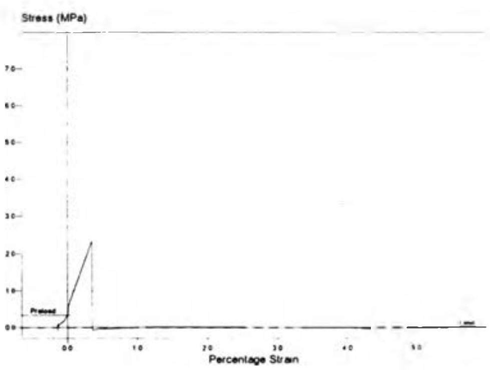

(c) 3 phr MMT




(f) 3 phr 2C18-MMT

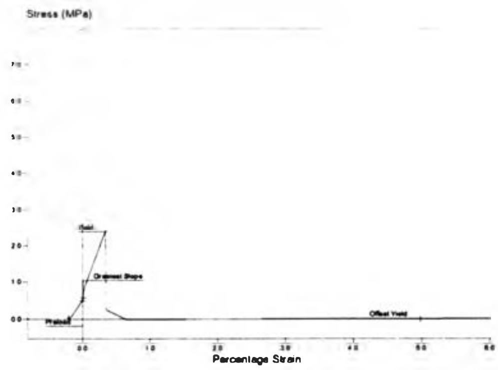



(d) 5 phr MMT

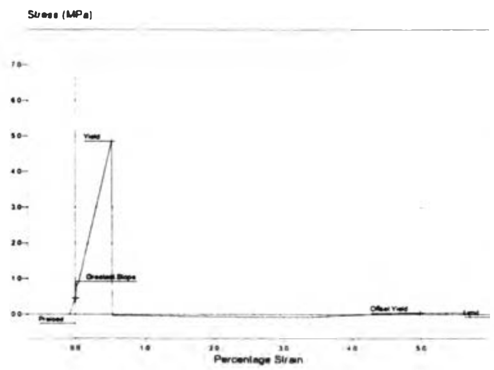



(g) 5 phr 2C18-MMT

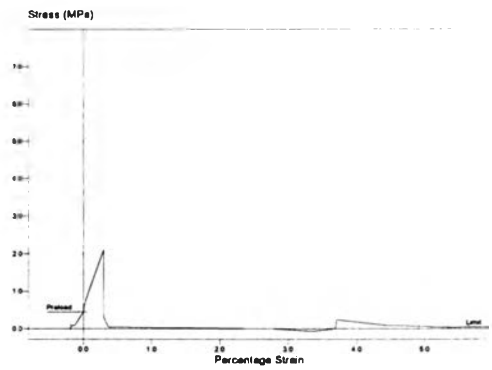
Figure C9 Effect of clay contents on tensile properties of PET/MMT hybrid films at 7% PET concentration in transverse direction (TD)



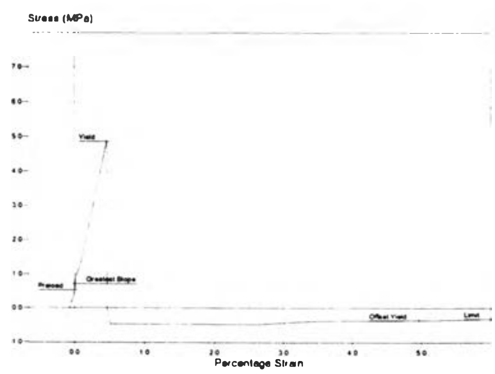

(a) Pure 7% PET films



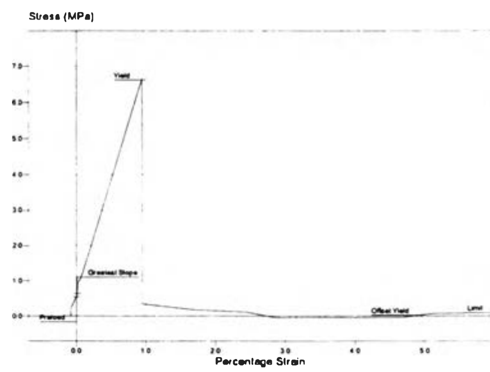

(b) 1 phr MMT



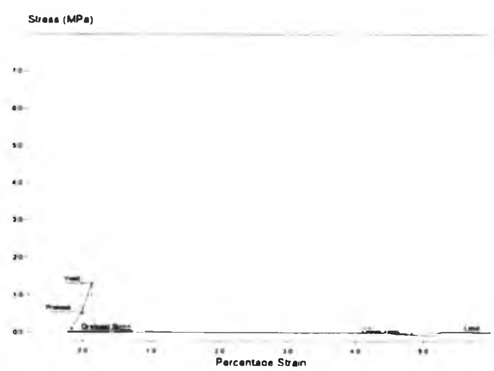

(e) 1 phr 2C18-MMT



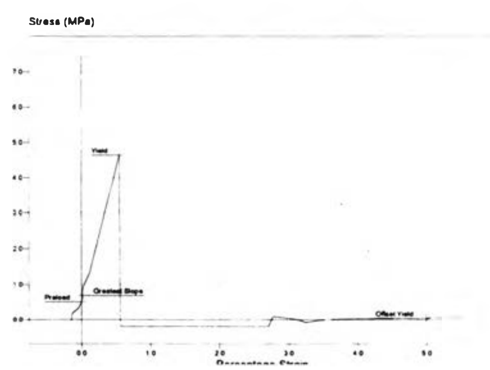

(c) 3 phr MMT




(f) 3 phr 2C18-MMT

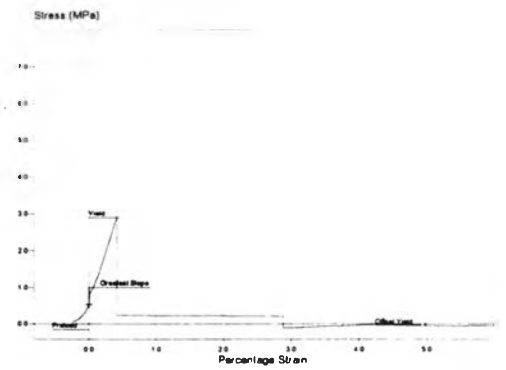



(d) 5 phr MMT

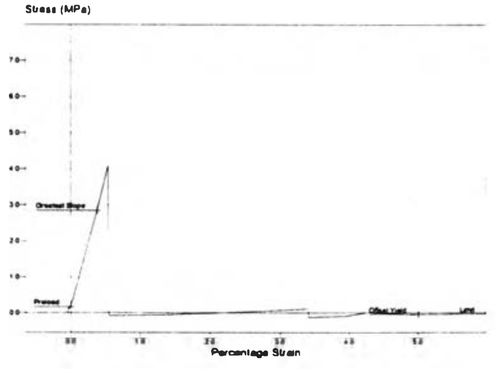



(g) 5 phr 2C18-MMT

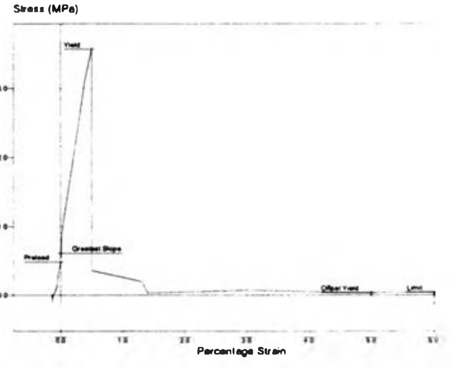
Figure C10 Effect of clay contents on tensile properties of PET/MMT hybrid films at 7% PET concentration in machine direction (MD)



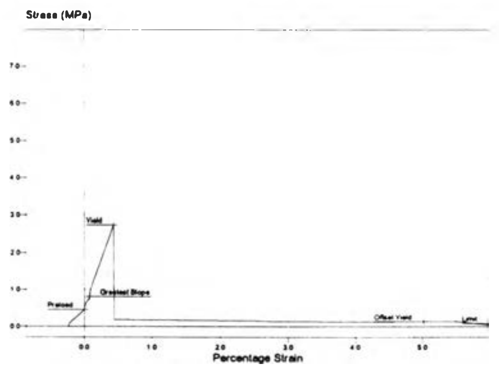

(a) Pure 9% PET films



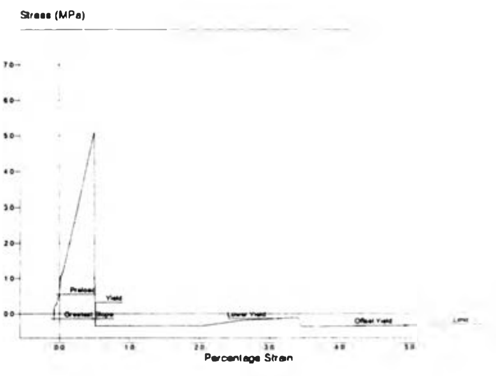

(b) 1 phr MMT



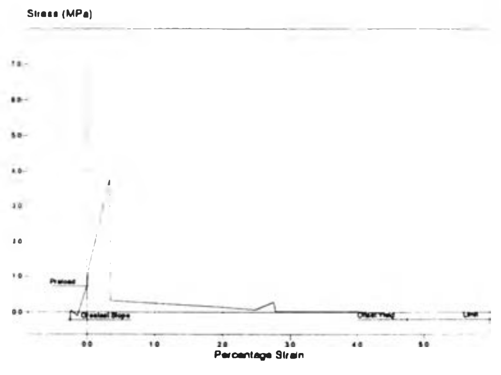

(e) 1 phr 2C18-MMT



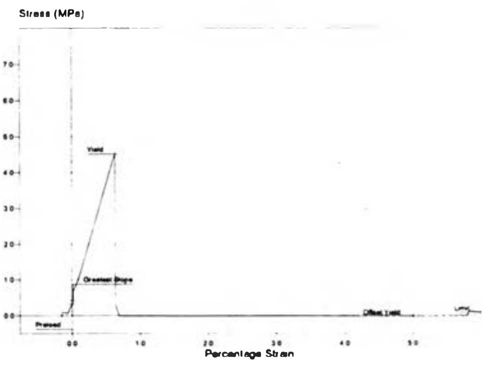

(c) 3 phr MMT




(f) 3 phr 2C18-MMT

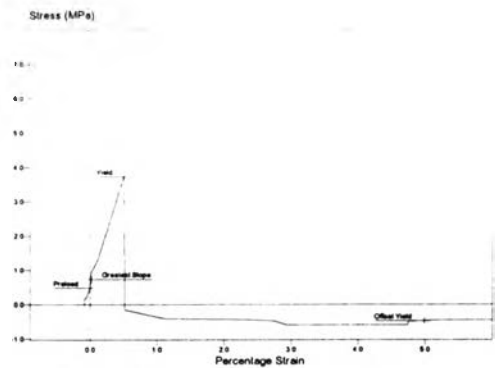



(d) 5 phr MMT

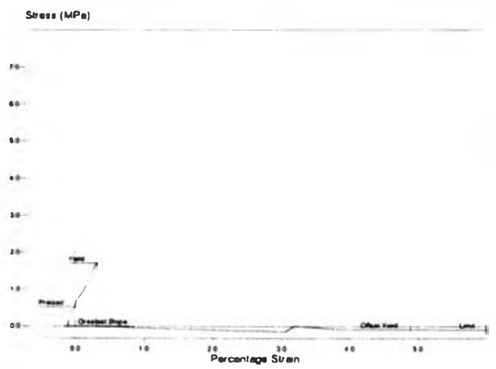



(g) 5 phr 2C18-MMT

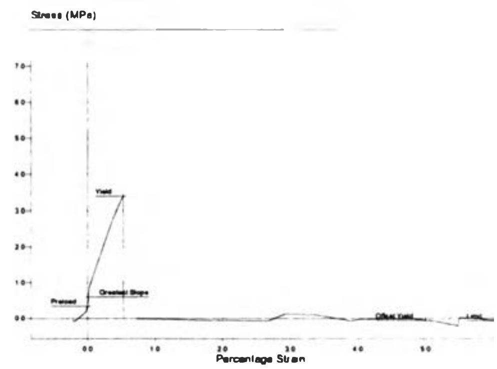
Figure C11 Effect of clay contents on tensile properties of PET/MMT hybrid films at 9% PET concentration in transverse direction (TD)



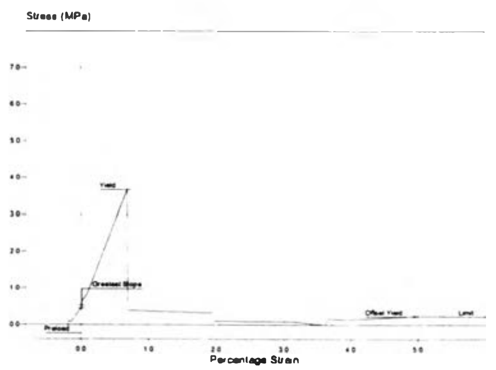

(a) Pure 9% PET film



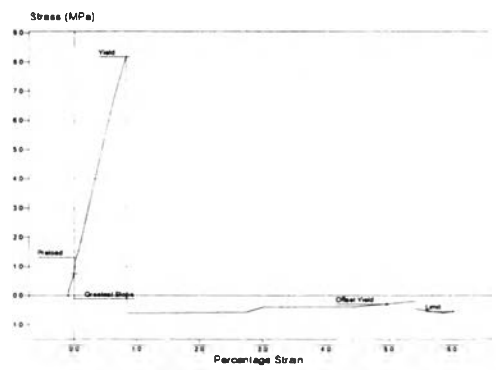

(b) 1 phr MMT



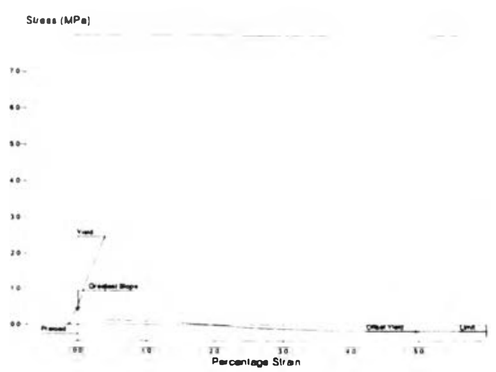

(e) 1 phr 2C18-MMT



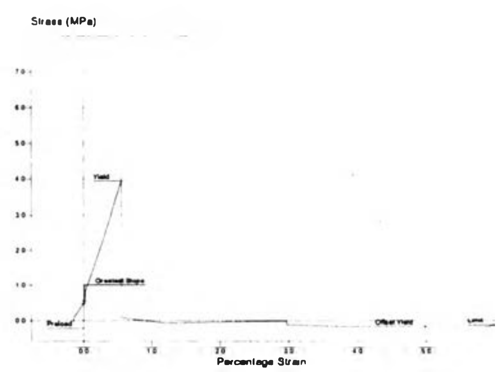

(c) 3 phr MMT




(f) 3 phr 2C18-MMT




(d) 5 phr MMT




(g) 5 phr 2C18-MMT

Figure C12 Effect of clay contents on tensile properties of PET/MMT hybrid films at 9% PET concentration in machine direction (MD)

# APPENDIX D

## THERMAL PROPERTIES

Differential Scanning calorimetry

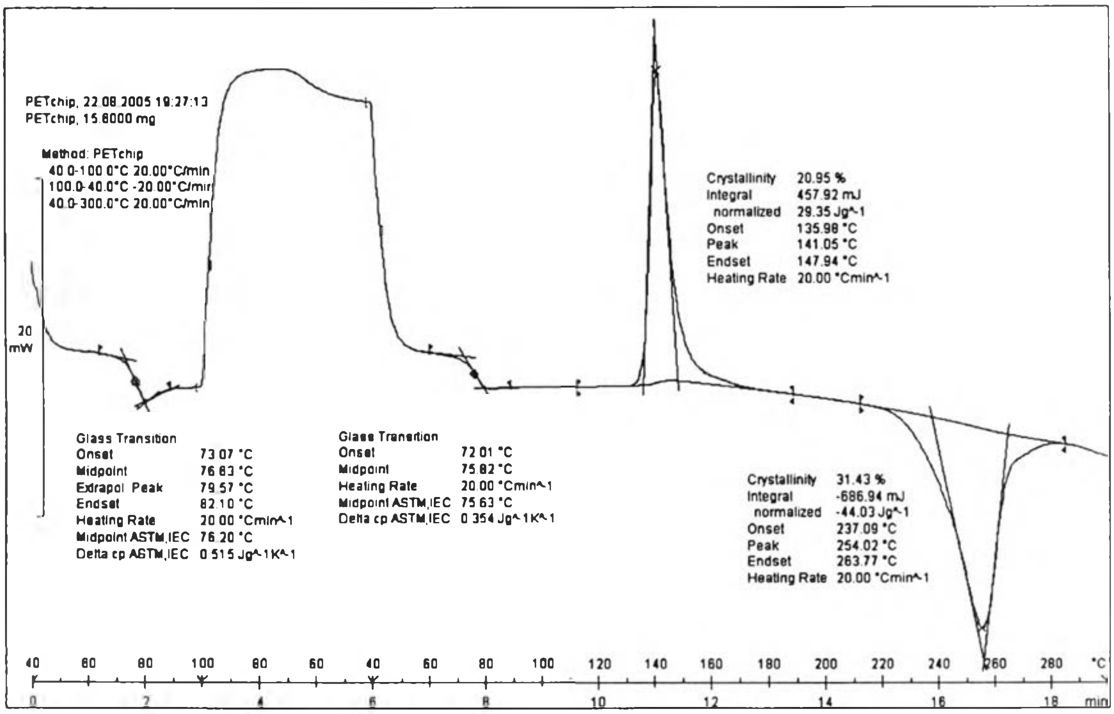



Figure D1 The DSC thermograms of PET chip (raw material)

# BIOGRAPHY

Miss Hathairat Benjapornthavee was born on 10th January 1981 in Bangkok, Thailand. She got her Bachelors of Science (Second Class Honors) degree majoring in Materials Science from the Department of Materials Science, Faculty of Science, Chulalongkorn University in March 2003. Further, she persuaded her post graduate degree at the Department of Materials Science, Faculty of Science, Chulalongkorn University in October 2003. She completed the programme and obtained her Master degree in Applied Polymer Science and Textile Technology in October 2005.