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Solid-state polymerization of a novel cyanate ester based on 4- tert -butylcalix[6]arene

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Abstract

© 2020 The Royal Society of Chemistry. A unique cyanate ester based on 4-ter--butylcalix[6]arene has been synthesized. It melts above 400 °C and polymerizes on heating above 300 °C, i.e., in the solid state. The techniques of FTIR, pXRD, NMR, MALDI, TGA, DSC, and fast scanning chip-calorimetry have been used to characterize the monomer and its polymerization. The kinetics of solid-state polymerization has been analyzed by an advanced isoconversional method that has revealed that the process rate is limited by a single step. The activation energy of the process has demonstrated an unusually large value, 380 ± 10 kJ mol-1, which points at cooperative breaking of CN bonds as the rate limiting step. This is in contrast to the regular cyanate esters that polymerize in the liquid-state by consecutive breaking of CN bonds. It has also been found that the polymerization follows zero-order kinetics, which is explained by the topochemical nature of polymerization localized on the surface of the plate-like crystals of the monomer.

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References

[1] A. Matsumoto T. Tanaka Mol. Cryst. Liq. Cryst. 2005 440 215 222
[2] M. Ikeshima H. Katagiri W. Fujiwara S. Tokito S. Okada Cryst. Growth Des. 2018 18 5991 6000
[3] G. W. Oakley S. E. Lehman J. A. Smith P. Van Gerven K. B. Wagener Macromolecules 2003 36 539 542
[4] M. Hasegawa Pure Appl. Chem. 1986 58 1179 1188
[5] H. Matsuzawa S. Okada A. Sarkar H. Matsuda H. Nakanishi Polym. J. 2001 33 182 189
[6] M. Kamath W. H. Kim L. Li J. Kumar S. Tripathy Macromolecules 1993 26 22 5954 5958
[7] R. R. Chance G. N. Patel J. Polym. Sci., Polym. Phys. Ed. 1978 16 859 881
[8] C. Shi S. M. Gross J. M. DeSimone D. J. Kiserow G. W. Roberts Macromolecules 2001 34 2060 2064
[9] M. A. G. Jansen J. G. P. Goossens G. De Wit C. Bailly C. Schick C. E. Koning Macromolecules 2005 38 10658 10666
[10] V. S. Iyer J. C. Sehra K. Ravindranath S. Sivaram Macromolecules 1993 26 1186 1187
[11] S. M. Gross G. W. Roberts D. J. Kiserow J. M. Desimone Macromolecules 2001 34 3916 3920
[12] N. Kasmi Z. Terzopoulou G. Z. Papageorgiou D. N. Bikiaris eXPRESS Polym. Lett. 2018 12 227 237
[13] S. N. Vouyiouka E. K. Karakatsani C. D. Papaspyrides Prog. Polym. Sci. 2005 30 10 37
[14] F. Guo J. Martì-Rujas Zh. Pan C. Hughes K. Harris J. Phys. Chem. C 2008 112 19793 19796
[15] V. Enkelmann, Advances in Polymer Science, Springer, Berlin, 1984, vol. 63, pp. 91-136
[16] L. R. MacGillivray, J. L. Atwood, J. W. Steed and G. S. Papaefstathiou, Encyclopedia of supramolecular chemistry, Marcel Dekker Inc., New York, 2004, pp. 1316-1319
[17] I. Hamerton, Chemistry and Technology of Cyanate Ester Resins, Chapman & Hall, Glasgow, 1994

[18] S. L. Simon J. K. Gillham J. Appl. Polym. Sci. 1993 47 461 485
[19] C. D. Gutsche J. Am. Chem. Soc. 1981 103 3782 3792
[20] S. Vyazovkin, Isoconversional Kinetics of Thermally Stimulated Processes, Springer, Switzerland, 2015
[21] S. Vyazovkin A. K. Burnham J. M. Criado L. A. Pérez-Maqueda C. Popescu N. Sbirrazzuoli Thermochim. Acta 2011 520 1 19
[22] S. Vyazovkin D. Dollimore J. Chem. Inf. Comput. Sci. 1996 36 42 45
[23] S. Vyazovkin J. Comput. Chem. 1997 18 393 402
[24] S. Vyazovkin J. Comput. Chem. 2001 22 178 183
[25] S. Vyazovkin, N. Koga and S. Christoph, Handbook of Thermal Analysis and Calorimetry, Elsevier, 2018, pp. 131-172
[26] G. I. Senum R. T. Yang J. Therm. Anal. 1977 11 445 447
[27] S. Vyazovkin C. A. White Anal. Chem. 2000 72 3171 3175
[28] N. Sbirrazzuoli Thermochim. Acta 2013 564 59 69
[29] S. Vyazovkin I. Dranca X. W. Fan R. Advincula Macromol. Rapid Commun. 2004 25 498 503
[30] S. Vyazovkin Int. J. Chem. Kinet. 1996 28 95 101
[31] M. L. Ramirez R. Walters R. E. Lyon E. P. Savitski Polym. Degrad. Stab. 2002 78 73 82
[32] S. Rakesh M. Sarojadevi Chem. Chem. Technol. 2008 2 239 247
[33] A. Saponar E. J. Popovici I. Perhaita G. Nemes A. I. Cadis J. Therm. Anal. Calorim. 2012 110 349 356
[34] L. Eddaif L. Trif J. Telegdi O. Egyed A. Shaban J. Therm. Anal. Calorim. 2019 137 529 541
[35] K. Chennakesavulu M. R. Basariya P. Sreedevi G. Bhaskar Raju S. Prabhakar S. S. Rao Thermochim. Acta 2011 515 24 31
[36] G. Casiraghi M. Cornia G. Ricci G. Balduzzi G. Casnati G. D. Andreetti Die Makromolekulare Chemie 1983 184 1363 1378
[37] S. Vyazovkin Phys. Chem. Chem. Phys. 2016 18 18643 18656
[38] J. D. Peterson S. Vyazovkin C. A. Wight Macromol. Chem. Phys. 2001 202 775 784
[39] A. E. Jablonski A. J. Lang S. Vyazovkin Thermochim. Acta 2008 474 78 80
[40] B. D. Park J. F. Kadla Thermochim. Acta 2012 540 107 115
[41] C. C. Chen T. M. Don T. H. Lin L. P. Cheng J. Appl. Polym. Sci. 2004 92 3067 3079
[42] A. Galukhin T. Liavitskaya S. Vyazovkin Macromol. Chem. Phys. 2019 220 1 8
[43] A. Osei-Owusu G. C. Martin J. T. Gotro Polym. Eng. Sci. 1992 32 535 541
[44] M. A. Ziganshin A. S. Safiullina A. V. Gerasimov S. A. Ziganshina A. E. Klimovitskii K. R. Khayarov V. V. Gorbatchuk J. Phys. Chem. B 2017 121 8603 8610
[45] B. Yancey S. Vyazovkin Phys. Chem. Chem. Phys. 2014 16 11409 11416
[46] Organic Solid-State Reactions, ed., F. Toda, Springer, Netherlands, 2002
[47] I. Tinoco, K. Sauer, J. Wang, J. Puglisi, G. Harbison and D. Rovnyak, Physical chemistry: principles and applications in biological sciences Pearson, 5th edn, 2014
[48] H. Melville H. Roxburgh J. Chem. Soc. 1933 586 595
[49] B. M. Novak A. K. Cederstav J. Macromol. Sci., Part A: Pure Appl.Chem. 1997 34 1815 1825
[50] M. B. Bassi A. B. Padias H. K. Hall Polym. Bull. 1990 24 227 232
[51] B. M. Chamberlain B. A. Jazdzewski M. Pink M. A. Hillmyer W. B. Tolman Macromolecules 2000 33 3970 3977
[52] L. R. Gilliom R. H. Grubbs J. Am. Chem. Soc. 1986 108 733 742
[53] D. J. Walsh S. H. Lau M. G. Hyatt D. Guironnet J. Am. Chem. Soc. 2017 139 13644 13647
[54] Reactions in the solid state, ed., M. Brown, D. Dollimore, and, A. Galwey, Elsevier, Netherlands, 1980