Impact of Aspect Ratio of Carbon Nanotubes on Shear and Extensional Rheology of Polyethylene Nanocomposites

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Abstract:
This paper reports the results of studies on the effect of aspect ratio of multiwall carbon nanotubes (CNT) on the shear and extensional rheological behavior of low density polyethylene (LDPE) nanocomposites. Up to a CNT loading of 2 wt%, as used in the present study, the shear rheological data suggest no network formation in the nanocomposites, irrespective of the aspect ratio of the nano filler. Dynamic shear viscosity η' increases with increase in loading and aspect ratio of CNT. However, at low CNT loadings (0.1 wt%) and with CNT of high aspect ratio, η' for the nanocomposites is found to be lower than that of neat polymer. Steady shear rheology results show negative values for the normal stress for the high aspect ratio CNT which is believed to be due to the tumbling of CNT with high aspect ratio. Results of extensional viscosity measurements show that extent of strain hardening is dependent on the CNT aspect ratio and follows the order, high aspect ratio > medium aspect ratio > short aspect ratio, while the time of break follows the reverse order. The effect of aspect ratio on critical extensional stress becomes prominent only at the high aspect ratio, but the stress increases with the increase in CNT loading, irrespective of the aspect ratio.

Zusammenfassung:
Dieser Artikel berichtet über die Resultate der Untersuchungen über den Einfluss des Aspektverhältnisses von mehrwandigen Kohlenstoffnanoröhrchen (CNT) auf das scher- und dehnrheologische Verhalten von Polyethylen niedriger Dichte (LDPE)-Nanokompositen. Bis zu einem CNT-Gehalt von 2 Gew. %, wie es in dieser Studie gegeben war, deuten die scherrheologischen Daten auf keine Netzwerkbildung in den Nanokompositen hin, unabhängig von dem Füllstoffgehalt der Nanopartikel. Die dynamische Scherviskosität η' nimmt mit dem CNT-Gehalt und dem Aspektverhältnis der Kohlenstoffnanoröhrchen zu. Jedoch ist bei niedrigen CNT-Anteilen (0,1 Gew. %) und bei CNT mit einem hohen Aspektverhältnis η' für die Nanokomposite niedriger als für das reine Polymer. Die stationäre Scherrheologie führt zu negativen Werten der Normalspannung für die CNT mit einem hohen Aspektverhältnis, was auf die Taumelbewegung der CNT mit einem hohen Aspektverhältnis zurückgeführt wird. Die Resultate der Dehnviskositätsmessungen zeigen, dass das Ausmaß der Dehnverfestigung von dem Aspektverhältnis der CNT abhängig ist und der Reihenfolge hohes Aspektverhältnis > mittleres Aspektverhältnis > niedriges Aspektverhältnis folgt, wohingegen die Zeit des Reissens der Probe der umgekehrten Reihenfolge folgt. Der Einfluss des Aspektverhältnisses auf die kritische Dehnspannung wird nur bei einem hohen Aspektverhältnis deutlich. Jedoch nimmt die Spannung mit dem CNT-Gehalt unabhängig von dem Aspektverhältnis zu.

Résumé:
Cet article présente les résultats d'études sur l'effet du facteur de forme des nanotubes de carbone multi-parois (CNT) sur le comportement rhéologique de cisaillement et d'extension de polyéthylène basse densité (LDPE) nanocomposites. Jusqu'à une charge de 2 CNT % poids, tel qu'il est utilisé dans la présente étude, les données rhéologiques de cisaillements ne suggèrent pas de formation de réseau dans les nanocomposites, quel que soit le rapport de forme de la charge nano. La viscosité de cisaillement dynamique η' augmente avec l'augmentation du taux de chargement et du rapport d'aspect des CNT. Toutefois, à faible charges CNT (0.1 en % poids) et pour des rapports d'aspect élevé de la CNT, η' pour les nanocomposites est inférieure à celle du polymère pur. Les résultats de rhéologie de cisaillement à l'état stationnaire présentent des valeurs négatives pour la contrainte normale pour les valeurs élevées du rapport d'aspect des CNT. Ceci est considéré comme étant due à la culbute du CNT pour les rapports d'aspect élevés. Les résultats des mesures de viscosité extensionnelle montrent que l'étendue de l'écrouissage dépend du facteur de forme des CNT et suit l'ordre, rapport d'aspect élevé > aspect ratio moyen > aspect ratio faible, alors que le temps de pause suit l'ordre inverse. L'effet du rapport d'aspect sur le stress extension critique ne devient important que pour un rapport d'aspect élevé, par ailleurs le stress augmente avec l'augmentation du chargement en CNT, quel que soit le format.

Key words: Polyethylene, nanocomposites, aspect ratio, rheology

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REFERENCES

[1] Rahmat M, Hubert P: Carbon nanotube–polymer interactions in nanocomposites: A review, Compos. Sci. Technol. 72 (2011) 72 – 84.

[2] Shawky HA, Chae S, Lin S, Wiesner MR: Synthesis and characterization of a carbon nanotube/polymer nanocomposite membrane for water treatment, Desalination 272 (2011) 46 – 50.

[3] Guo W, Liu C, Sun X, Yang Z, Kia HG, Peng H: Aligned carbon nanotube/ polymer composite fibers with improved mechanical strength and electrical conductivity, J. Mater. Chem. 22 (2012) 903 – 908.

[4] Metin C, Bonnecaze R, Nguyen Q: Shear Rheology of Silica Nanoparticle Dispersions, Appl. Rheol. 21 (2011) 13146.

[5] Nazockdast E, Nazockdast H: Rheological Modeling of Polymer/layered silicate nanocomposites, Appl. Rheol. 21 (2011) 25434.

[6] Galgali G, Ramesh C, Lele A: A rheological study on the kinetics of hybrid formation in polypropylene nanocomposites, Macromol. 34 (2001) 852 – 858.

[7] Lim YT, Park OO: Rheological evidence for the microstructure of intercalated polymer/layered silicate nanocomposites, Macromol. Rapid Commun. 21 (2000) 231 – 235.

[8] Hyun YH, Lim ST, Choi HJ, Jhon MS: Rheology of poly(ethylene oxide)/organoclay nanocomposites, Macromol. 34 (2001) 8084 – 8093.

[9] Kitano T, Hashmi SAR, Chand N: Dynamic viscoelastic properties of organic/inorganic fibres reinforced LLDPE composites in molten state, Appl. Rheol. 11 (2001) 258 – 263.

[10] Krishnamoorti R, Ren J, Silva AS: Shear response of layered silicate nanocomposites, J. Chem. Phys. 114 (2001) 4968 – 4973.

[11] Ray SS, Bousmina M, Okamoto K: Structure and properties of nanocomposites based on poly(butylene succinate-co-adipate) and organically modified montmorillonite, Macromol. Mater. Eng. 290 (2005) 759 – 768.

[12] Ray SS, Bousmina M: Poly(butylene sucinate-co-adipate)/ montmorillonite nanocomposites: effect of organic modifier miscibility on structure, properties, and viscoelasticity, Polymer 46 (2005) 12430 – 12439.

[13] Susteric Z, Kos T: Rheological Idiosyncrasies of Elastomer/Clay Nanocomposites, Appl. Rheol. 18 (2008) 54894.

[14] Ren J, Casanueva BF, Mitchell CA, Krishnamoorti R: Disorientation Kinetics of aligned polymer layered silicate nanocomposites, Macromol. 36 (2003) 4188 – 4194.

[15] Cortes P, Lozano K, Barrera EV, Bonilla-Rios J: Effect of nanofiber treatments on the properties of vapor grown carbon fiber reinforced polymer composites, J. Appl. Polym. Sci. 89 (2003) 2527 – 2534.

[16] Lozano K, Yang S, Zeng Q: Rheological analysis of vapor grown carbon nanofiber reinforced polyethylene composites, J. Appl. Polym. Sci. 93 (2004) 155 – 162.

[17] Lee SH, Cho E, Jeon SH, Youn JR: Rheological and electrical properties of polypropylene composites containing functionalized multi-walled carbon nanotubes and compatibilizers, Carbon 45 (2007) 2810 – 2822.

[18] McNally T, Potschke P, Halley P, Murphy M, Martin D, Bell SEJ, Brennan GP, Bein D, Lemoine P, Quinn JP: Polyethylene multiwalled carbon nanotube composites, Polymer 46 (2005) 8222 – 8232.

[19] Kim JA, Seong DG, Kang TJ, Youn JR: Effects of surface modification on rheological and mechanical properties of CNT/epoxy composites, Carbon 44 (2006) 1898 – 1905.

[20] Kharchenko SB, Douglas JF, Obrzut J, Grulke EA: Flow-induced properties of nanotubes filled polymer materials, Nature Mater. 3 (2004) 564 – 568.

[21] Xu DH, Wang ZG: Influence of carbon nanotube aspect ratio on normal stress difference in isotactic polypropylene nanocomposite melts, Macromol. 41 (2008) 815 – 825.

[22] Ibnelwaleed H, Williams M: Rheological study of heterogeneities in melt blends of ZN-LLDPE and LDPE: Influence of Mw and comonomer type, and implications for miscibility, Rheol. Acta. 43 (2004) 602 – 614.

[23] Xiao KQ, Zhang LC, Zarudi I: Mechanical and rheological properties of carbon nanotube reinforced polyethylene composites, Compos. Sci. Technol. 67 (2007) 177 – 182.

[24] Seo MK, Park SJ: Electrical resistivity and rheological behaviors of carbon nanotubes-filled polypropylene composites, Chem. Phys. Lett. 395 (2004) 44 – 48.

[25] Valentino O, Sarno M, Rainone NG, Nobile MR, Ciambelli P, Neitzert HC, Simon GP: Influence of polymer structure and nanotube concentration on the conductivity and rheological properties of polyethylene/CNT composites, Physica E 40 (2008) 2440 – 2445.

[26] Guth W: Theory of filler reinforcement, J. Appl. Phys. 16 (1945) 20 – 25.

[27] Mackay ME, Dao TT, Tuteja A, Ho DL, Van Horn B, Kim H-C, Hawker CJ: Nanoscale effects leading to non-Einstein-like decrease in viscosity, Nature Mater. 2 (2003) 762 – 766.

[28] Tuteja A, Mackay ME, Hawker CJ, Van Horn B: Effect of ideal, organic nanoparticles on the flow properties of linear polymers: non-Einstein like behavior, Macromol. 38 (2005) 8000 – 8011.

[29] Tang Y, Gao P, Ye L, Zhao C: Organoclay-modified thermotropic liquid crystalline polymers as viscosity reduction agents for high molecular mass polyethylene, J. Mater. Sci. 45 (2010) 5353 – 5363.

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http://www.appliedrheology.org

[30] Jain SH: Nano-scale events with macroscopic effects in polypropylene/silica nanocomposites; effect of polymer adsorption on processability and properties, Ph.D. Thesis, Technische Universiteit Eindhoven (2005).
[31] Laske S, Witschnigg A, Mattausch H, Kracalik M, Pinter G, Feuchter M, Maier G, Holzer C: Determining the ageing of polypropylene nanocomposites using rheological measurements, Appl. Rheol. 22 (2012) 24590 – 24599.
[32] Magda JJ, Lou J, Baek SG: 2nd normal stress difference of a Boger fluid, Polymer 32 (1991) 2000 – 2009.
[33] Magda JJ, Baek SG: Concentrated entangled and semi dilute entangled polystyrene solutions and the 2nd normal stress difference, Polymer 35 (1994) 1187 – 1194.
[34] Gunes DZ, Scirocco R, Mewis J, Vermant J: Flow-induced orientation of non-spherical particles: Effect of aspect ratio and medium rheology, J. Non-Newtonian Fluid Mech. 155 (2008) 39 – 50.
[35] Li Y, Kröger M, Liu WK: Nanoparticle geometrical effect on structure, dynamics and anisotropic viscosity of polyethylene nanocomposites, Macromol. 45 (2012) 2099 – 2112
[36] Karatrantos A, Composto RJ, Winey KI, Clarke N: Structure and conformations of polymer/SWCNT nanocomposites, Macromol. 44 (2011) 9830 – 9838.
[37] Araki K, Kitano T, Hausnerova B: Rheological properties of carbon fiber and carbon black filled liquid crystalline polymer melts, Appl. Rheol. 11 (2001) 188 – 196.
[38] Zatloukal M: Novel Trends in Rheology IV, Appl. Rheol. 21 (2011) 367 – 368.
[39] Larson RG: Arrested tumbling in shearing flows of liquid crystal polymers, Macromol. 23 (1990) 3983 – 3992.
[40] Lee SH, Cho ER, Jeon SH, Youn JR: Rheological and electrical properties of polypropylene composites containing functionalized multi-walled carbon nanotubes and compatibilizers, Carbon 45 (2007) 2810 – 2822.
[41] Liang J-Z, Zhong L: Estimation of elongation viscosity of polyethylene melts, J. Thermoplastic Compos. Mater. 24 (2011) 367 – 376.
[42] Filip P, Svrcinova P: Measurement of elongational viscosity of polymer melts using SER Universal Testing Platform, Appl. Rheol. 22 (2012) 14776
[43] Haworth B, Jumpa S, Miller NA: Melt-state elongational rheometry of mineral-filled polyethylene, Polym. Test. 19 (2000) 459 – 477.
[44] Münstedt H, Laun HM: Elongational properties and molecular structure of polyethylene melts, Rheol. Acta. 20 (1981) 211 – 221.

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