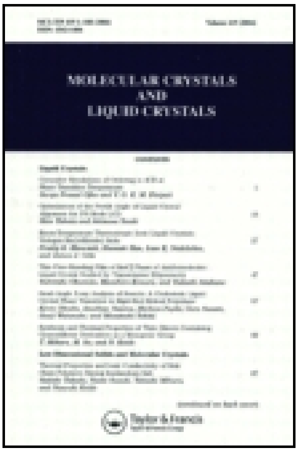

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Electromechanical Strain Responses of SEBS/CB and SEBS/SWCNT Composites

Il Jin Kim [a b], Jiyoung Jung [a c], Soon Man Hong [a c] & Chong Min Koo [a c]

[a] Nano Hybrids Research Center, Korea Institute of Science and Technology, P. O. Box 131, Cheongryang, Seoul, Republic of Korea

[b] Department of Chemical and Biological Engineering, Korea University, Sung buk - gu, Seoul 136-701, Seoul, Republic of Korea

[c] Nanomaterials Science and Engineering, University of Science and Technology, 176 Gajung-dong, 217 GajungoYuseong-gu, Daejeon, Republic of Korea

Version of record first published: 12 Sep 2012.

To cite this article: Il Jin Kim , Jiyoung Jung , Soon Man Hong & Chong Min Koo (2012): Electromechanical Strain Responses of SEBS/CB and SEBS/SWCNT Composites, Molecular Crystals and Liquid Crystals, 566:1, 135-140

To link to this article: http://dx.doi.org/10.1080/15421406.2012.701875

Mol. Cryst. Liq. Cryst., Vol. 566: pp. 135–140, 2012
Copyright © Taylor & Francis Group, LLC
ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2012.701875

Electromechanical Strain Responses of SEBS/CB and SEBS/SWCNT Composites

IL JIN KIM,[1,2] JIYOUNG JUNG,[1,3] SOON MAN HONG,[1,3,*] AND CHONG MIN KOO[1,3]

[1]Nano Hybrids Research Center, Korea Institute of Science and Technology, P. O. Box 131, Cheongryang, Seoul, Republic of Korea
[2]Department of Chemical and Biological Engineering, Korea University, Sung buk - gu, Seoul 136-701, Seoul, Republic of Korea
[3]Nanomaterials Science and Engineering, University of Science and Technology, 176 Gajung-dong, 217 GajungoYuseong-gu, Daejeon, Republic of Korea

*Electromechanical strain responses of poly (styrene-*b*-ethylbutylene-*b*-styrene) (SEBS) /carbon black (CB) composites and SEBS/single wall carbon nanotube (SWCNT) composites were investigated. The electric field induced thickness strains s_z of the composites increased with the conductive filler content at the low filler concentration region and then showed the maximum. s_z represents relative thickness change relative to the initial thickness of the composite film. A further increase of the filler concentration caused a decrease in the actuation strain. The SEBS/SWCNT showed a larger s_z than SEBS/CB at the same filler content.*

Keywords Dielectric; electromechanical strain; SWCNT; carbon; space charge injection.

1. Introduction

Electroactive dielectric elastomers have been paid a great deal of attention as potential actuators, owing to their outstanding properties such as high electromechanical actuation strain, fast response, high power-to-mass ratio and easy processibility [1–5]. In particular, Shankar and coworkers reported that an electroactive nanostructured poly (styrene-*b*-ethylbutylene-*b*-styrene) (SEBS) gel in where glassy styrene micelles served as physical crosslinks, showed excellent electromechanical performance as well as a great tunability of their properties [4,7,8]. However, the outstanding actuation performance has still been achieved at very high applied electric field strength, which is considered an obstacle for real application.

Many dielectric elastomer composite systems with conductive fillers have been proposed in order to reduce the operational voltage by means of increasing the dielectric constant [6–9]. Zhang and coworkers reported that poly (vinylidenefluoride-*co*-trifluoroethylene-*co*-chlorofluoroethylene) composites with conductive carbon nanotubes achieved a robust actuation strain [6]. Such actuation performance enhancement was

---

[*] Address correspondence to S. M. Hong, phone: 82 2 958 5315; fax 82 2 958 5309. E-mail: smhong@kist.re.kr

attributed to a higher dielectric constant of the composites in comparison to a matrix polymer. Huang and Zhang reported that poly (vinylidenefluoride-*co*-trifluoroethylene-*co*-chlorofluoroethylene) copolymer with polyaniline conducting polymer fillers showed a dramatic increase in the dielectric constant near the percolation threshold concentration and a big increase in the electromechanical actuation strain [7]. In contrast, Guiffard et al. claimed that though polyurethane with a small amount of conductive carbon powder fillers had almost the same dielectric constant as neat polyurethane, the electric actuation properties of the composites were significantly enhanced in the presence of the conductive fillers owing to the space-charge effect [8–11]. Nonetheless, the origins of the enhanced actuation of the composite systems with the conductive fillers are not yet fully understood.

This presentation introduces two types of fillers of single wall carbon nanotube (SWCNTs) with a rod shape and carbon black (CB) nanopowders to SEBS dielectric elastomers in order to investigate the effect of conductive fillers on the electromechanical actuation properties of the SEBS dielectric elastomers.

2. Experimental

2.1 Materials

The poly(styrene-b-ethylbutylene-b-styrene) (SEBS) (G1650) triblock copolymer shown in Fig. 1was purchased from KRATON. It is a thermoplastic elastomer with 30 wt% styrene hard end blocks and 70 wt% ethylbutylene soft middle block. White mineral oil (T-150) was obtained by Michang Oil Ind. Co. in Korea. The carbon nanopowder (Denka black) (CB) and single wall carbon nanotubes (AST-100F) (SWCNTs) used as conductive fillers were purchased from DENKA and Hanhwa Nanotech, respectively. The CB had average primary particle diameter of 36 nm and specific surface area of 65 m^2/g. The SWCNTs had average tube diameter of 1.0–1.2 nm and average tube length of 5–20 μm. The carbon paste (FTU-20) used as compliant electrodes was purchased from Asahi Chemicals.

2.2 Preparation of the SEBS/CB and SEBS/SWCNT composites

The SEBS gel consisted of 20 wt% neat SEBS and 80 wt% mineral oil. The SEBS/CB and SEBS/SWCNT composites contained a predetermined filler content ranging from 0.02 wt% to 10 wt% in the SEBS gel. The sample name, SEBS/CB0.2 denoted the composite consisting of SEBS gel and 0.2 wt% CB fillers. The composites were blended using ball milling with zirconium balls. A mixture of SEBS gel, conductive fillers and toluene medium in a bowl was milled at 400 rpm for 1 hour. After ball-milling, it was dried in a vacuum oven. The sample films 0.5 mm thick were prepared using hot pressing molding. Compliant carbon paste electrodes were coated on both sides of the composite films by spin-coating. The average thickness of the compliant electrodes was 10 μm.

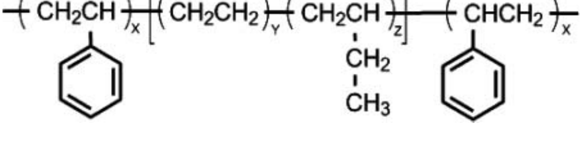

Figure 1. Chemical structure of SEBS

2.3 Characterizations

The dielectric constant of the composite films was measured by an impedence analyzer (HP1492A) at 100 Hz to 10 kHz at room temperature, respectively. The electromechanical thickness strain of the composites was measured using two laser displacement sensors (Keyence LK-G80) under the application of a voltage step. The detailed thickness strain measurement setup was described in the previous literature [18,19]. For the electromechanical strain measurement, the composite films with carbon paste electrodes were mounted between the rigid frames with a 30 mm diameter. The electric voltage was delivered to the film using a function generator, the Agilent 33250A amplified by a factor of 1000 through a high-voltage lock-in amplifier, and a Trek 10/10B.

3. Results and Discussion

Figure 2 shows the dielectric constants of SEBS/CB and SEBS/SWCNT at various filler contents. The neat SEBS gel had a dielectric constant of 2.36 at room temperature. The dielectric constants of both composites increased with the filler concentration. However, the increase rate of the dielectric constant with filler content was different in each composite. The dielectric constant of the SEBS/CB composites slowly increased with the CB content. The SEBS/CB composite with CB fillers of 1 wt% had a dielectric constant of about 2.5. In contrast, the dielectric constant of the SEBS/SWCNT composites rapidly increased with filler content even at a very low SWCNT concentration. The SEBS/SWCNT composites showed a much faster increase rate of the dielectric constant than the SEBS/CB composites. The SEBS/SWCNT1.0 with SWCNT of 1 wt% had a dielectric constant of about 3.0. Interestingly, the dielectric loss factor of every sample in this work was kept below 0.05 even at high filler concentrations.

Figure 3a shows the electromechanical thickness strain s_z of neat SEBS, SEBS/CB0.2 and SEBS/CB0.5 as a function of the electric field. The initial sample thickness was 500 μm. The s_z of the neat SEBS gel increased with an increased strength of the applied electric field. The SEBS/CB0.2 composite containing a CB content of 0.2 wt% showed a higher s_z than the SEBS at the same electric field strength. Interestingly, the SEBS/CB0.5 composite

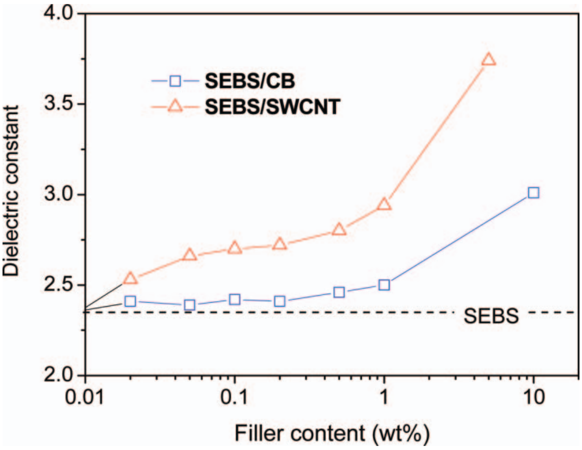

Figure 2. Dielectric constants of SEBS/CB and SEBS/SWCNT composites at various filler concentrations.

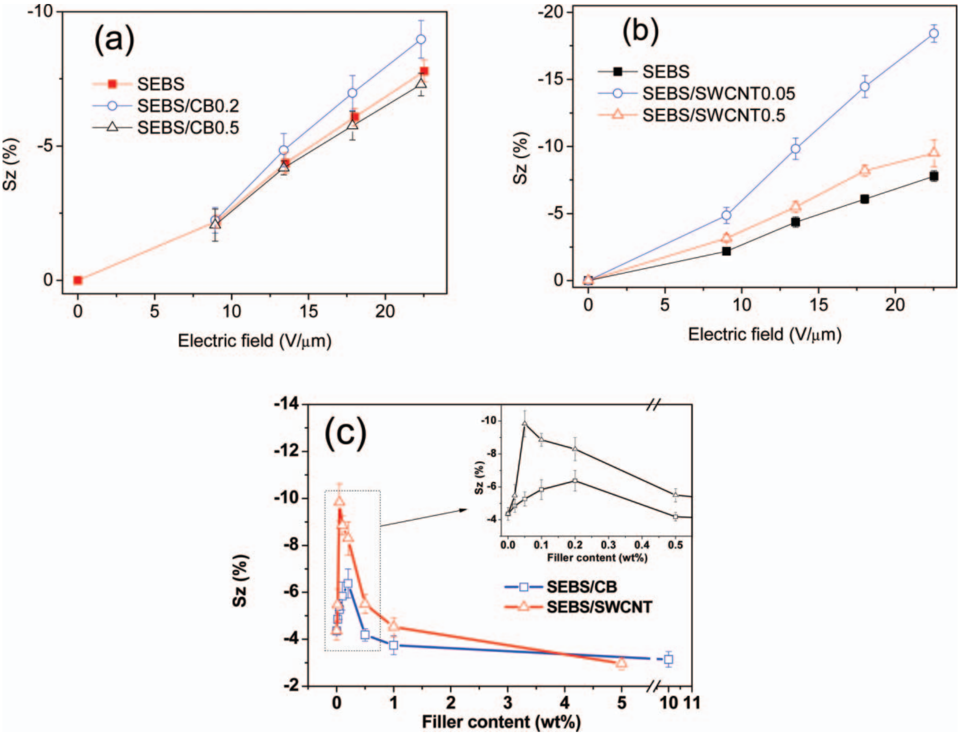

Figure 3. The electromechanical thickness strains, s_z of (a) SEBS/CB composites and (b) SEBS/SWCNT composites as a function of the applied electric field, and thickness strains of (c) SEBS/CB and SEBS/SWCNT composites with various filler content at a constant electric field of 13 V/μm.

with a CB content of 0.5 wt% showed a smaller s_z than the SEBS/CB0.2 with a CB content of 0.2 wt% at the same electric field strength. Similarly, in Fig. 3b, the SEBS/SWCNT0.05 composites with a SWCNT content of 0.05 wt% showed a much higher s_z than the SEBS at the same electric field strength. However, the SEBS/SWCNT0.5 showed a smaller s_z than the SEBS/SWCNT0.05 at the same electric field strength. Figure 3c shows s_z of the SEBS/CB and SEBS/SWCNT composites as a function of filler content at constant electric field strength of 13 V/μm. The s_z of the SEBS/CB composite rapidly increased with the CB content until 0.2 wt% and then decreased with a further increase in CB content. The s_z of the SEBS/ SWCNT composite also rapidly increased with the SWCNT content until 0.05 wt% and then decreased with a further increase in SWCNT content. The SEBS/SWCNT composite showed a larger s_z than the SEBS/CB at the same filler content.

The SEBS/SWCNT composites showed a larger s_z than the SEBS/CB at the whole range of filler level in this experiment. It was attributed to two reasons. One was the conductivity difference between the CB and the SWCNTs. SWCNTs are well known as conductive fillers with higher electric conductivity than CB. Thus, it was expected that the SWCNTs would be better conductive fillers than the CB in the composites so that the SEBS/SWCNTs had not only a higher dielectric constant but also larger electric actuation responses than the SEBS/CB. The other reason was the shape difference between the two fillers. The SWCNTs had a long rod shape (1D morphology) with a high aspect ratio. The

SWCNTs had a tube diameter of 1.0–1.2 nm and a tube length of 5–20 μm. In contrast, the CB was isotropic and had amorphous carbon particles (0D morphology). The SWCNTs with a high aspect ratio acted as more effective fillers than the CB with a low aspect ratio, because as the aspect ratio increased, not only the effective surface area but also the hydrodynamic volume of the filler increased [20,21]. That is to say, the electric actuation of the composites was considerably influenced not only by the electric conductivity of fillers but also by the filler shape. The SWCNTs with a higher conductivity and shape anisotropy played as more effective conductive fillers than the CB with a lower conductivity and isotropic shape.

Interestingly, the actuation strain peak maximum appeared in Fig. 3c. The reason of the strain peak maximum is not clear yet. However, high conductivity of the used fillers can be considered as one of the most possible reasons. Both CB and SWCNT were conductive fillers. As the filler concentration increases, the dielectric stability of the composites becomes unstable. That is, the dielectric break-down electric field of the composites decreases with filler content. The enhancement of the dielectric instability of the composite films at a high filler content could be attributed to the reason why electric actuation performance of the composite films became reduced at a high filler concentration.

4. Conclusion

The electric actuation properties of poly (styrene-*b*-ethylbutylene-*b*-styrene) (SEBS) /carbon black (CB) and SEBS/single wall carbon nanotube (SWCNT) composites were investigated. The electromechanical thickness strains and elastic energy densities of the composites increased with the conductive filler concentration up to certain point and then decreased at a high concentration. The electric actuation of the composites was considerably influenced not only by the electric conductivity of the fillers but also by the filler shape. SWCNTs with higher conductivity and shape anisotropy were more effective fillers than CB with lower conductivity and isotropic shape.

Acknowledgements

This work was financially supported by a grant from the Fundamental R&D Program for Core Technology of Materials funded by the Ministry of Knowledge Economy, Republic of Korea and partially by a grant from the Hybrid Materials Research Center of the Korea Institute of Science and Technology (KIST).

References

[1] Pelrine, R., Kornbluh, R., & Joseph, J. (1998). Electrostriction of polymer dielectrics with compliant electrodes as a means of actuation. *Sensors and Actuators A*, *64*, 77–85.

[2] Pelrine, R., Kornbluh, R., Pei, Q, & Joseph, J. (2000). High speed electrically actuated elastomers with strain greater than 100%. *Science*, *287*, 836–389.

[3] Pelrine, R., Kornbluh, R., Joseph, J., Heydt, R., Pei, Q., & Chiba, S. (2000). High field deformation of elastomeric dielectrics for actuators. *Mater. Sci. Eng. C*, *11*, 89–100.

[4] Shankar, R., Ghosh, T. K., & Spontak, R. J. (2007). Dielectric elastomers as next generation polymeric actuators. *Soft Matter*, *3*, 1116–1129.

[5] Koo, I. M., Jung, K., Koo, J. C., Nam, J. Do., Lee, Y. K., & Choi, H. R. (2008). Development of soft actuator based wearable tactile display. *IEEE Trans. Robot.*, *24*, 549–558.

[6] Kwak, J. W., Chi, H. J., Jung, K. M., Koo, J. C., Jeon, J. W., Lee, Y. K., Nam, J. D., & Choi, H. R. (2005). A face robot actuated with artificial muscle based on dielectric elastomer. *J. Mech. Sci. Tech.*, *19*, 578–588.

[7] Shankar, R., Ghosh, T. K., & Spontak, R. J. (2007). Electroactive nanostructured polymers as tunable actuators. *Adv. Mater.*, *19*, 2218–2223.

[8] Shankar, R., Krishnan, A. K., Ghosh, T. K., & Spontak, R. J. (2008). Triblock copolymer organogels as high performance dielectric elastomers. *Macromolecules*, *41*, 6100–6109.

[9] Carpi, F., & Rossi, D. (2005). Improvement of electromechanical actuating performances of a Silicone dielectric elastomer by dispersion of titanium dioxide powder. *IEEE Trans. Dielec. Elec.* Insul., *12*, 835–843.

[10] Zhang, Q., Li, H., Poh, M.. Xia, F., Cheng, Z. Y., Xu, H., & Huang, C. (2002). An all-organic composite actuator material with a high dielectric constant. *Nature*, *419*, 284–287.

[11] Huang, C., & Zhang, Q. (2005). Fully functionalized high dielectric constant nanophase polymers with high electromechanical response. *Adv. Mater.*, *17*, 1153–1158.

[12] Huang, C., & Zhang, Q. (2004). Enhanced dielectric and electromechanical responses in high dielectric constant all polymer percolative composites. *Adv. Funct. Mater.*, *14*, 501–506.

[13] Zhang, S., Zhang, N., Huang, C., Ren, K., & Zhang Q. (2005). Microstructure and electromechanical properties of carbon nanotube / poly(vinylidene fluoride-trifluoroethylene-chlorofluoroethylene). composites. *Adv. Mater.*, *17*, 1897–1901.

[14] Guiffard, B., Seveyrat, L., Sebald, G., & Guyomar, D. (2006). Enhanced electric field induced strain in non-percolative carbon nanopowder/polyurethane composites. *J. of Phys. D: Appl. Phys.*, *39*, 3053–3057.

[15] Guiffard, B., Guyomar, D., Seveyrat, L., Chowanek, Y., Bechelany, M., Cornu, D. & Miele, P. (2009). Enhanced electroactive properties of polyurethane films loaded with carbon coated SiC nanowires. *J. of Phys. D: Appl. Phys.*, *42*, 055503.

[16] Su, J., Ting, R. Y., & Zhang, Q. M. (1997). Space charge enhanced electromechanical responses in thin film polyurethane elastomers. *Appl. Phys. Lett.*, *71*, 386–388.

[17] Carbone, A., Kotowska, B. K., & Kotowski, D. (2005). Space charge limited current fluctuations in organic semiconductors. *Phys. Rev. Lett.*, 95, 236601.

[18] Kim, B., Park, Y. D., Kim, J., Hong, S. M., & Koo, C. M. (2010). Measuring true electromechanical strain of electroactive thermoplastic elastomer gels using synchrotron SAXS. *J. Polym. Sci. Part. B : Polym. Phys.*, *48*, 2392–2398.

[19] Guillot, F. M., Jarzynski, J., & Balizer, E. (1998). Electromechanical response of polymer films by laser Doppler vibrometry. *J. Acoust. Soc. Am.*, *103*, 1421–1427.

[20] Lim, Y. T., & Park, O. O. (2000). Rheological evidence for the microstructure of intercalated polymer/layered silicate nanocomposites. *Macromol. Rapid Commun.*, *21*, 231–235.

[21] Koo, C. M., Kim, M. J., Choi, M. H., Kim, S. O., & Chung, I. J. (2003). Mechanical and rheological properties of the maleated polypropylene-layered silicate nanocomposites with different morphology. *J. Appl. Polym. Sci.*, *88*, 1526–1535.

[22] Pope, M., & Swemberg, C. E. (1998). *Electronic Processes in Organic Crystal and Polymer* (Oxford University Press, Oxford).