

STUDY OF THERMOMECHANICAL EFFECTS OF MAIN CHAIN LIQUID CRYSTAL ELASTOMER AS FUNCTION OF CROSSLINKER CONCENTRATION

Irna Farikhah^{1,2} and Yusril Yusuf¹

¹Department of Physics, Faculty of Mathematics and Natural Sciences-Gadjah Mada University
Sekip Utara, BLS 21, Bulaksumur, Yogyakarta 55281, Indonesia

²Department of Physics, Faculty of Mathematics and Natural Sciences-IKIP PGRI Semarang
Sidodadi Timur 24, Semarang 55125, Indonesia
e-mail : irnafarikhah@yahoo.co.id

ABSTRACT

STUDY OF THERMOMECHANICAL EFFECTS OF MAIN CHAIN LIQUID CRYSTAL ELASTOMER AS FUNCTION OF CROSSLINKER CONCENTRATION. Thermomechanical effects of dry Main Chain Liquid Crystal Elastomer (MCLCE) with the different concentration of crosslinker 8 %, 12 %, 14% and 16% have been studied. Length of MCLCE monotonically shrinks parallel to the director, while it expands perpendicularly to the director, with a somewhat faster change at nematic isotropic transition phase, T_{ni} . The result of the investigation showed that the value of maximum contraction is greater and faster than maximum expansion.

Key words : Main Chain Liquid Crystal Elastomers (MCLCE), Thermomechanical effects, Function of crosslinker concentration

ABSTRAK

STUDI EFEK TERMOMEKANIK RANTAI UTAMA DARI ELASTOMER KRISTAL CAIR SEBAGAI FUNGSI KONSENTRASI *CROSSLINKER*. Efek termomekanik dari rantai utama pada elastomer kristal cair kering (*MCLCE*) dengan konsentrasi *crosslinker* yang berbeda pada 8 %, 12 %, 14 % dan 16 % telah dipelajari. Panjang dari *MCLCE* secara monoton memendek paralel terhadap *director*, namun memanjang secara tegak lurus terhadap *director*, dengan perubahan yang cepat pada fasa transisi *nematic isotropic* (T_{ni}). Hasil dari penelitian ini menunjukkan bahwa nilai kontraksi maksimal lebih besar dan lebih cepat dari ekspansi maksimal.

Kata kunci : Main Chain Liquid Crystal Elastomers (*MCLCE*), Efek termomekanik, Fungsi konsentrasi *crosslinker*

INTRODUCTION

The invention of Liquid Crystal (LC) by Friedrich Reinitzer in 1888 had improved the research of its properties. Some properties of LC had been investigated especially in molecular structure and electrical response of LC. It was not until the early 1970s that the successful commercialization of a pocket calculator with a display of device that utilized liquid crystals sparked an intense interest in the field [1].

In the last twenty years, the interest of LC has blossomed and incorporated with varied material. In this point, Liquid Crystal Elastomers (LCE) was developed and improved, which LC is a unique material with special properties combination LC and rubber properties. The elastic properties of LCE

made it very potential to be developed as artificial muscles [1,2].

LCE was synthesized first by Finkelmann at 1981 and had been improved until the invention of Main Chain Liquid Crystal Elastomer (MCLCE) [2,3]. Polydomain Side Chain Liquid Crystal Elastomer (SCLCE) was the first LCE which was invented and then developed to be monodomain SCLCE. After the invention of SCLCE, the research of LCE was growing until the discovery of monodomain MCLCE [4].

As early as 1975, De Gennes predicted qualitatively the extraordinary mechanical and optical properties that should be expected from nematic MCLCE, where the mesogenic units are connected

within the polymer backbone to build up the polymer network [5].

One of the most outstanding features of nematic elastomers is a reversible change in length at the nematic to isotropic phase transformation for monodomain samples that are macroscopically ordered with respect to the director. This change in shape is due to the coupling of the liquid crystalline order with the polymer chain conformation of the network. The coupling has been investigated in detail for SCLCE [6,7], where the mesogenic moieties are attached as side groups to the monomer units of the network. However, only few investigations have been performed on main 56 chain elastomers [8].

There had been substantial research on the SCLCE. Based on result, the effects of SCLCE was still relatively small so that we need another type of LCE in order to obtain the larger effects to be applied on artificial muscle. MCLCE is one of the LCE type that has been predicted to be more appropriate to be applied as artificial muscle.

EXPERIMENTAL METHOD

The polydomain MCLCE was synthesized in a one-step reaction, by dissolving the monomer 2-ethyl-1,4-phenylene bis [4-[4-(vinyl)oxy] butoxy] benzoate ($C_{34}H_{38}O_6$) and 8 %, 12 %, 14 % and 16 %, the chain extender 1,1,3,3,-tetramethyldisiloxane ($C_{14}H_{14}OSi_2$). Monodomain MCLCE was prepared in three types crosslinking concentration, 8 %mol, 12 %mol, 14 %mol and 16 %mol of the crosslinking agent pentamethylcyclopentasiloxane ($C_5H_{10}O_5Si_5$) in toluene. The monodomain MCLCE was obtained by mechanical stretching in order to obtain the uniform director orientation, \hat{n} , parallel to the stretching direction.

To measure the length changes of LSCE during the variation of temperature, we prepared type of rectangular LSCE sample that is slicing parallel to \hat{n} (planar sample). The sample is observed by a microscope (Nikon) equipped with a temperature controller. The image of each temperature photographed during the heating and cooling processes with a range between 30 °C until 120 °C for 8 %mol, 12 %mol, 14 %mol and 16 %mol of the crosslinking agent.

MCLCE samples were placed in glass. Samples are monodomain MCLCE. Monodomain planar MCLCE was obtained from cutting sample parallel with the director, \mathbf{n} . A polarizing microscope was used to observe the thermo-mechanical effects which linked to a CCD camera and a PC (Personal Computer). CCD camera was used to take the picture of thermomechanical effects and the picture was saved in the PC.

RESULTS AND DISCUSSION

Figure 1 shows the observation of thermomechanical effects of MCLCE with 8 %, 12 %, 14 % and 16 % cross linking concentrations, through heating and cooling.

The anisotropic thermomechanical effects for MCLCE samples during the heating and the cooling

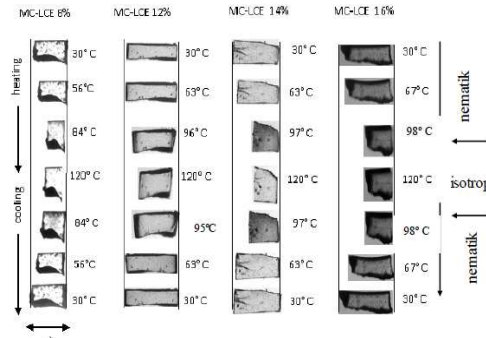


Figure 1. Thermo-mechanical effect induced shape changes of MCLCE for planar samples. MCLCEs shrink on heating and expand on cooling (parallel the director), $\parallel \mathbf{n}$. In contrast, MCLCEs expand $\perp \mathbf{n}$ on heating and shrink on cooling

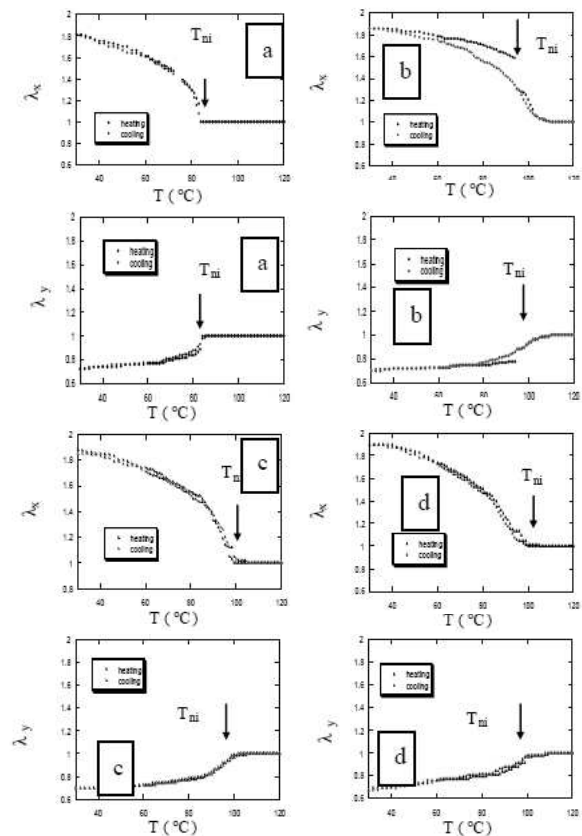


Figure 2. Temperature dependence of the relative length changes, $\lambda_{\parallel \mathbf{n}}$ and $\lambda_{\perp \mathbf{n}}$ for dry MCLCE-8, MCLCE-12, MCLCE-14 and MCLCE-16 samples during the heating and the cooling processes. The drastic length changes are observed at T_c ($T_{MCLCE-8} \sim 84^\circ\text{C}$, $T_{MCLCE-12} \sim 95^\circ\text{C}$, $T_{MCLCE-14} \sim 97^\circ\text{C}$ and $T_{MCLCE-16} \sim 98^\circ\text{C}$), the apparent nematic-isotropic phase transition temperature of the dry MCLCE.

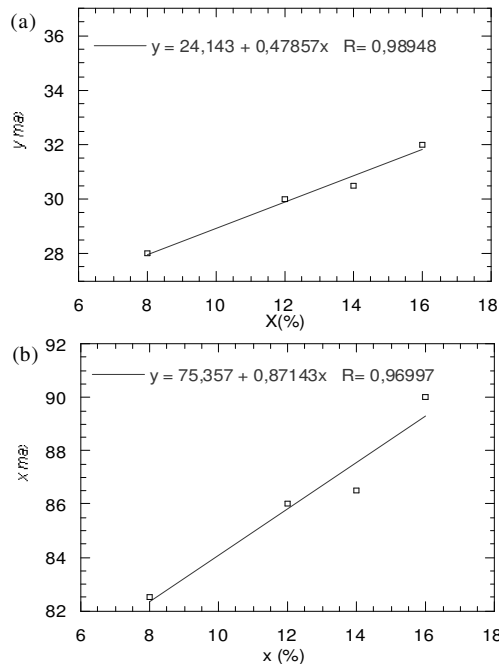


Figure 3. The dependence of the maximum length change, λ_{\max} , on the concentration of crosslinking, X%, of MCLCEs in the isotropic is plotted. (a) maximum expansion, $\lambda_{y \max}$ and (b). maximum contraction, $\lambda_{x \max}$

processes are shown in this figure. When increasing the temperature, the planar samples shrink parallel to $\hat{n}(\hat{x})$ and expand perpendicular to $\hat{n}(\hat{y})$. After cooling, all samples returned to their original shape.

Figure 2 shows the relative length changes of MCLCEs parallel to $\hat{n}(\hat{x})$ and as a function of temperature. Upon increasing temperature, all samples monotonically shrank parallel to $\hat{n}(\hat{x})$ with a somewhat faster decrease in the vicinity of T_c ($T_c^{\text{MCLCE-8}} \sim 84^\circ\text{C}$, $T_c^{\text{MCLCE-12}} \sim 95^\circ\text{C}$, $T_c^{\text{MCLCE-14}} \sim 97^\circ\text{C}$ and $T_c^{\text{MCLCE-16}} \sim 98^\circ\text{C}$).

The relative length changes of planar samples as a function of temperature, $\lambda_i(T)$ is defined as the ratio of expansion/shrinkage length to the initial length in the isotropic phase ($T = 120^\circ\text{C}$). Length measurements were made in the middle of each edge far from the other edges. The relative error was $\sim \pm 1\%$ due to the pixel size of the photo micrograph.

The maximum expansion was in the direction perpendicular to $\hat{n}(\hat{y})$ (Figure 3(a)). The maximum expansion is about 28 % for MCLCE 8 %, 30 % for MCLCE 12 %, 30.5 % for MCLCE 14 % and 32 % for

MCLCE 16 %. In contrast, MCLCE monotonically shrink (parallel to $\hat{n}(\hat{x})$) is about 82.5 % for MCLCE 8 %, 86 % for MCLCE 12 %, and 86.5 % for MCLCE 14 % and 90 % for MCLCE 16 % (Figure 3(b)).

CONCLUSION

This work has shown that thermo-mechanical effects of MCLCE is a function of cross linker concentration of MCLCE. The effects showed in the changes of length. There are maximum expansion and contraction. Result of the investigation showed that the value of maximum contraction is greater and faster than the maximum expansion.

ACKNOWLEDGMENT

We wish to thank Simon Krause and Heino Finkelmann for sending us some of the samples used in these measurements. This work is partially supported by Hibah Bersaing DIKTI 2009 and Hibah Kompetensi DIKTI 2009.

REFERENCES

- [1]. H. KAWAMOTO, *Proc. IEEE*, **90** (4) (2002) 460-500
- [2]. P. G. DE GENNES, *The Physics of Liquid Crystals*, Clarendon Press, Oxford, 2nd Edition, (1993)
- [3]. M. WARNER and E.M. TERENTJEV, *Liquid Crystal Elastomers*, Clarendon Press, Oxford, (2003)
- [4]. H. FINKELMANN, H.J. KOCK and G. REHAGE, *Macromol. Chem.*, **2** (1981) 317
- [5]. Y. YUSUF, Y. ONO, Y. SUMISAKI, P.E. CLADIS, H.R. BRAND, H. FINKELMANN and S. KAI, *Phys. Rev. E*, **69** (2004) 021710
- [6]. Y. YUSUF, Y. SUMISAKI and S. KAI, *Chemical Physics Letters*, **382** (2003) 198
- [7]. Y. YUSUF, *Swelling Dynamics and Electromechanical Effects of Liquid Crystal Elastomers as An Artificial Muscle*, *Ph.D. Thesis Kyushu University Jepang*, (2005)
- [8]. M. A. ROLANDO, *Adsorption and Diffusion in Nanoporous Materials*, CRC Press Taylor and Francis Group, NW Suite 300, (2007)