Electrical Actuation of Textile Polymer Materials

Toshihiro Hirai[1*], Takamitsu Ueki[1], Midori Takasaki[2*]

[1] *Faculty of Textile Science and Technology, Shinshu University, Tokida 3-15-1, Ueda-shi 386-8567, Japan*
[2] *Venture Business Laboratory, Shinshu University, Tokida 3-15-1, Ueda-shi 386-8567, Japan*

Abstract: Polymers used in textiles were found to be effective as actuator materials with large deformation. Particularly, the polymers with low dielectric constants used to be considered inactive to electric field were turned out to be efficient actuator materials. They were classified into three types; (1) polymer gels swollen with solvents, (2) plasticized polymers, (3) bulk polymers. From the viewpoint of easy-to-operate, polymer gel deformation with swelling and deswelling was excluded here. Swollen dielectric gels could be electrically deformed by solvent drag that induced asymmetric pressure distribution in the gels. Bending and crawling motions were observed in these materials. In the case of plasticized polymers, especially in the case of poly(vinyl chloride) with plasticizers, amoeba-like reversible creep deformation was found, and the strain with over several hundreds of percent was detected. The material was stable and could have been operated for over two years. Bulk polymer film like poly(ethylene terephthalate) was found to oscillate under an application of dc electric field. Of course, the Maxwell force induced elastic contractile deformation can be expected in all cases.
The variation of the electrically induced deformation in dielectric polymer materials were demonstrated to be vast and expected application fields are also spread widely, particularly as artificial muscles.

Keywords: actuator, dielectric polymer, artificial muscle, polyethylene terephthalate, polyvinyl chloride, gels, plasticizer

1. Introduction

Electroactive actuators have been investigated on various materials, usually on electroactive inorganic compounds such as lead zirconium titanate. A polymer with relatively large dielectric constant and high crystallinity such as poly(vinylidene chloride) has also been investigated. Non-crystal or amorphous polymers with low dielectric constant are considered to be inactive to electric field, and polymers used commonly for textiles are usually classified in electrically non-active materials.

When we turned our eyes to soft polymer materials, gels have been investigated as efficient soft-actuator materials [1]. They are expected to be a kind of artificial muscles [2]. Various kinds of triggers are available such as (1) solvent exchange that can induce remarkable volume changes are pH, temperature, solubility, ionic strength, etc., and (2) internal pressure distribution without volume change such as electrically induced asymmetric distribution of ionic species. Gels are convenient as motility controllable materials, although the deformation accompanied solvent diffusion process is inconvenient as a device.

Deformation of the type (2) is practically adequate. So we have been investigating the non-swelling type actuation of soft polymer materials under the application of electric field. From this point of view, elastomers without solvent is attractiave.

In this review paper, we summarize the electrically active dielectric polymer actuators as polymer gels, plasticized polymers, and elastomers.

2. Gels

2.1 PVA-PAA Gel

Poly(vinyl alcohol) (PVA) blended or crosslinked with poly(acrylic acid) and can be hydro gels that can be actuated in salt solutions by applying dc electric field [3]. Deformation occurred with low electric field such as 2-10 V/mm, and with a current

* Corresponding author's email: *tohirai@shinshu-u.ac.jp, *mitakas@shinshu-u.ac.jp

of around 10-100 mA/cm^2. Responding time is in the range of seconds. Mechanism of the bending deformation has been explained by the asymmetric pressure distribution induced by the solvation of ionic spieces in the solution. Figure1 shows the principles of the deformation. Similar concepts can be applied in the case of ionic polymer – metal composite (IPMC) materials in which the migration of solvated ion caused an asymmetric pressure distribution in the composite membrane and resulting in bending deformation of the composite, but the strain could not be sustained and reduced under the continuing field application [4]. Typical ionic polymers are Nafion and/or Flemion. This relaxation is originated by the redistribution of the asymmetrically distributed solvated solvent. Solvent (water) content is lower in the case of IPMC than PVA-PAA gel, and IPMC is applicable in air actuation for as long as some amount of water remained in the IPMC. In water containing hydrophilic polymer actuators, however, dehydration caused depression of the actuation or inactivation of the actuators, and the presence of water is inevitable.

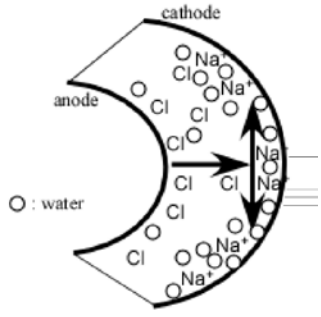

Figure 1 Electric field application induced the migration of solvated Na+ ion toward cathode side, and an asymmetric pressure distribution in the gel, thus caused bending deformation. Solvated water diffuse back according to the gradient of itself, thus, the deformation can not be sustained stable. Ionic speaces exist irrespective to the presence of the electric field. Current is in the range of mA.

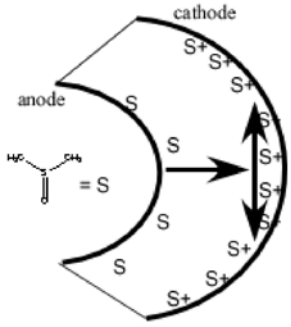

Figure 2 Swift bending deformation of PVA-DMSO gel by applying an electric field. Charges injected to DMSO are transferred to counter electrode side and brought about asymmetric pressure in the gel that can cause bending deformation. Strain is held stable as long as the field is on. Ionic speaces appear by field application, and dissappear when the field is off.

2.2 PVA-DMSO Gel

Dimethyl sulphoxide (DMSO) has no ionizable group and is dielectric solvent that can solubilize poly(vinyl alcohol) (PVA). By immersing chemically crosslinked PVA in DMSO, PVA-DMSO gel can be prepared [5]. In the case of PVA-DMSO gel, evaporation of DMSO is far slower than that of water and was stable in this sense. Dielectric constants of water and DMSO are 80 and 40 for water and DMSO, respectively. When the electric field was applied to the gel sheet, on which thin gold film was attached on both sides of the surfaces as electrodes, bent very efficiently. 90 degree bending was attained within 30 ms by applying an electric field of 250 V/mm . The current is around 10-100 micro A/cm^2 [6]. (Figure 2) The gel also showed a crawling deformation by placing the gel on a glass plate on which thin metal electrode array was aligned. These deformations were attained because of the charge injected solvent drag. The injected charges from an electrode migrate toward counter electrode accompanying solvated solvent, and thus formed asymmetric pressure distribution in the gel caused the bending and contractile deformations. Different from hydrophilic ionic gels and IPMC, the strain can be held as long as the field is on. It has been clarified by detailed analysis that the deformation accompanied electrorheological phenomenon induced by solvent drag of solvent in the gel [7]. (Figure 3)

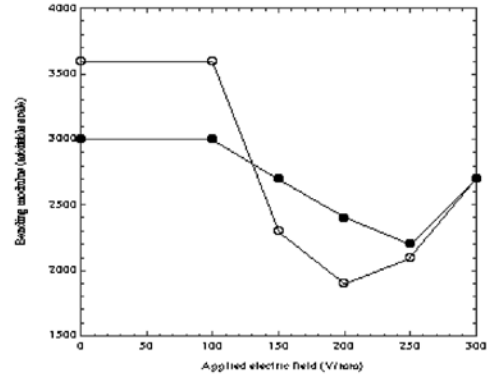

Figure 3 PVA-DMSO gel changes its bending modulus in the deformation process induced by an electric field application.

JFBI Vol.1 No. 1 2008 doi:10.3993/jfbi06200801