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Yu, Liyun; Jeppe Madsen, Peter; Boucher, Sarah ; Skov, Anne Ladegaard

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Enhancing the electro-mechanical properties of polydimethylsiloxane elastomers through blending with poly(dimethylsiloxane-co-methylphenylsiloxane) copolymers

Liyun Yu, Peter Jeppe Madsen, Sarah Boucher, Anne Ladegaard Skov

Danish Polymer Centre, Department of Chemical and Biochemical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

Abstract

Dielectric elastomers (DE) hold great promise as materials for novel, advanced electromechanical applications such as actuators, generators and sensors. Choosing the right polymer for the blending approach is of utmost importance to improve the electro-mechanical properties of DEs. In a study in our laboratories shows that sub-percentage additions of various aromatic substances can increase electrical breakdown strength significantly via voltage stabilisation, due to an electron trapping effect. In this work, improved electro-mechanical properties of silicone-based dielectric elastomers are achieved by means of adding co-called "voltage-stabilisers" prepared from phenyl-functional copolymers prepared using oxanyionic ring-opening polymerisation of octamethylcyclotetrasiloxane (D4) and either tetramethyltetraphenylcyclotetrasiloxane (T4) or octaphenylcyclotetrasiloxane (O4). The concentration of the voltage stabiliser was varied both by changing the molar ratio between methyl and phenyl groups in the copolymer and also by varying the amount of copolymer mixed into a polydimethylsiloxane (PDMS) based elastomer. The phenyl-functional copolymers were generally found to disperse homogeneously in the PDMS matrix and this resulted in networks with improved mechanical and electrical properties.

Keywords: electro-mechanical properties, silicone dielectric elastomer, voltage stabiliser, phenyl functionalised copolymer, blend

1. Introduction

2. Experimental

Fig. 1: Unpolarised dipoles randomly aligned in the elastomeric matrix.

Fig. 2: Re-orientation of polarised dipoles in the elastomeric matrix.

Fig. 3: The enhancement of electrical breakdown strength due to electron-trapping: (a) a silicone elastomer with an aromatic group grafted to the silicone backbone and a coating of conductive electrical tape on the top and bottom surfaces. (b) The absence of electrons at the interfaces between the elastomer and the compliant electrode in the presence of an electrical field. (c) The electron-trapping effect as a consequence of a collision between electrons and the phenyl group. (d) The formation of anion radicals resulting from the disturbance of the cloud of electrons in the phenyl group.

Fig. 4: Anionic Ring-Opening Polymerisation of cyclosiloxanes in the presence of N,N-dimethylamidamide as a polymerisation promoter.

Fig. 5: Cross-linked elastomers consisting of phenyl-PDMS copolymer in PDMS matrix and structures of the added phenyl-PDMS copolymers.

3. Results

Fig. 6: (A) Average Li-NMR spectra in the range 0.1 - 1.5 ppm for D4 (yellow), T4 (purple), MNS-H111 (blue), DMS-V531 (red) and PDT_7525 (blue). (B) Partial 1H NMR spectra of PD, PDT_5050 copolymers and the related monoblock copolymer 1200gA4, PDMS prepared by step-wise polymerisation as reported earlier. (C) Partial NCOX spectrum of PDT_5050 showing through-space correlations between aromatic protons and methyl protons.

4. Conclusions

The developed elastomers were inherently extensible with enhanced tensile and tear strengths, due to phenyl-rich microphases acting as reinforcing domains. Furthermore, addition of phenyl-functional copolymers resulted in elastomers with increased relative permittivity and electrical breakdown strength compared to control elastomers while retaining a low dielectric loss. This demonstrates their efficiency as voltage stabilisers.