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Electrical breakdown phenomena of dielectric elastomers

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Abstract

Silicone elastomers have been heavily investigated as candidates for dielectric elastomers and are as such almost ideal candidates with their inherent softness and compliance but they suffer from low dielectric permittivity.[1] This shortcoming has been sought optimized by many means during recent years. However, optimization with respect to the dielectric permittivity solely may lead to other problematic phenomena such as premature electrical breakdown. In this work, we focus on the **chloro propyl functionalized silicone elastomers** prepared in Madsen et al[2] and we investigate the **electrical breakdown** patterns of two similar chloro propyl functionalized silicone elastomers which break down electrically in a rather different way as well as we compare them to a silicone based reference. Scanning Electron Microscopy (**SEM**) and Energy Dispersive X-Ray Spectroscopy (**EDS**) are used to evaluate the elastomers after electrical breakdown.

Keywords: silicone elastomers, dielectric, electrical breakdown, voltage stabilization, characterization

1 Background

Recent studies have shown that by incorporation of dipolar moieties in minute amounts the electrical breakdown strength of silicone elastomers can be increased. Such studies include incorporation of chloro propyl groups on the silicone backbone.

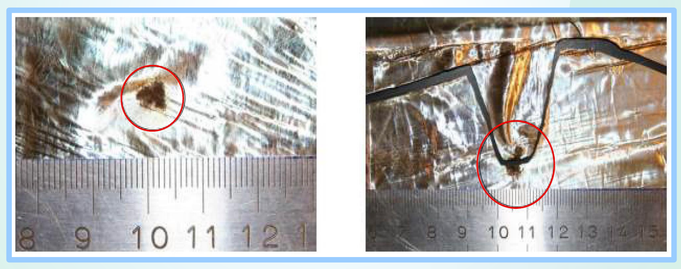

Figure 1. Electrical breakdown causes a pinhole formation on DEs film leading to major damage of the DE based devices.

2 Experimental

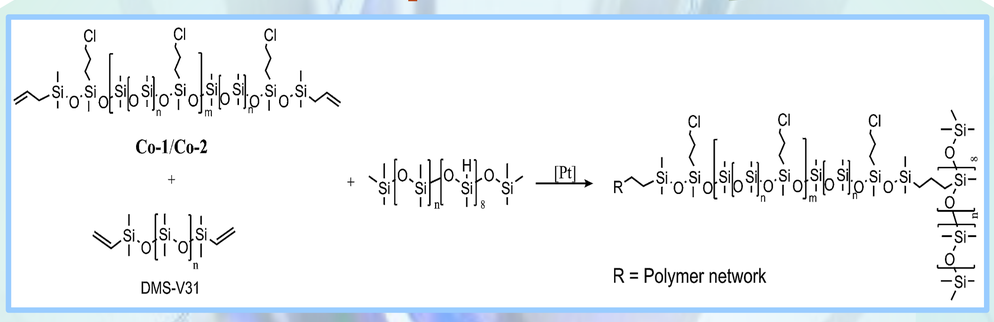

Figure 2. The structure of chloro propyl functional silicone elastomer..

Table 1. Details of prepared silicone elastomers.

Sample	Molecular weight between crosslinking sites (g mol^{-1})	Concentration of chloro propyl groups (wt%)	$E_{breakdown}$ (V µm^{-1})	Y@5% strain (MPa)	Tensile strength (MPa)	Strain at break (%)	ε_r @0.1Hz
DMS-V31 reference	28000	**0**	82	1.81	6.08	374	3.3
Co-1	29000	**2.0**	74	0.15	0.65	429	4.7
Co-2	29000	**3.6**	94	0.52	1.27	314	5.1

3 Testing

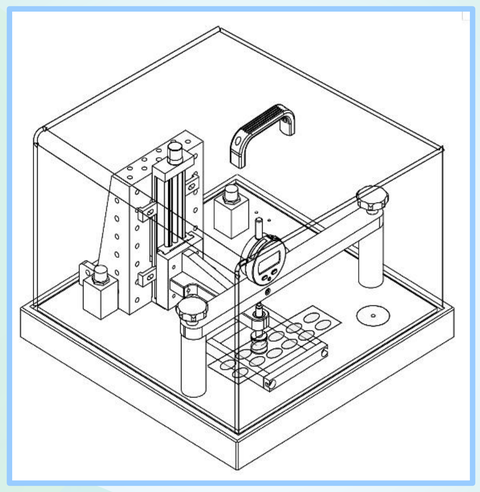

Figure 3. Breakdown Strength Instrument (spherical electrodes, stainless steel, diameter of 20 mm).

4 SEM

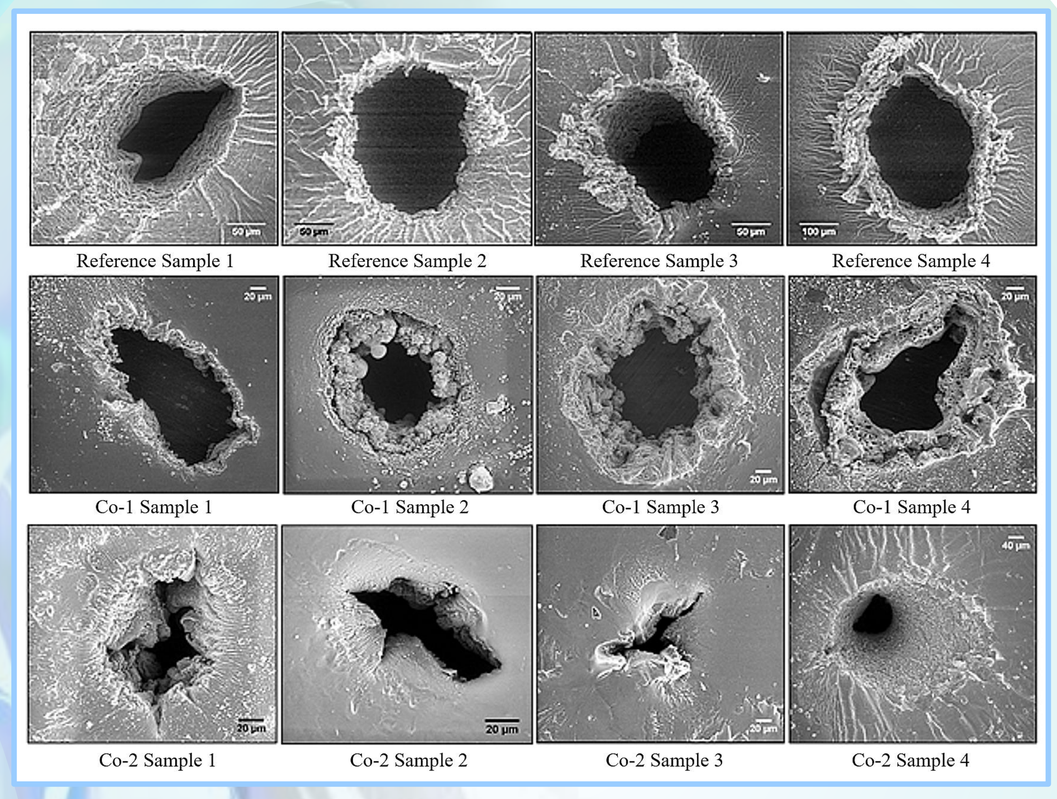

Figure 4. SEM images of breakdown zones for reference samples, Co-1 and Co-2 silicone elastomers. The black areas correspond to areas where the elastomer was completely removed during breakdown, i.e. pinholes. The white areas are solidified material with high silicium content.

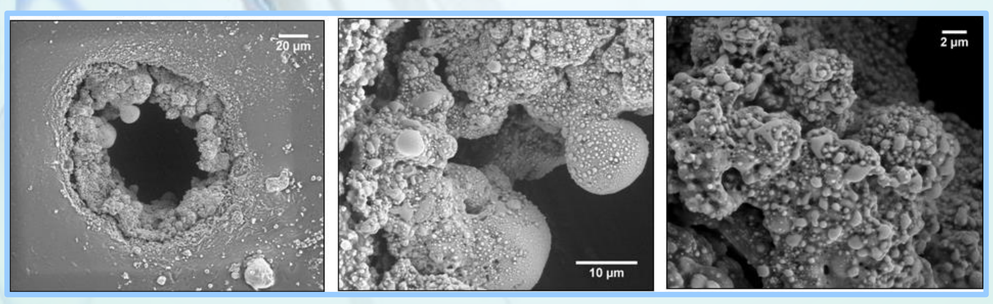

Figure 5. Illustration of boiling nature of the crosslinked copolymer Co-1 in different magnifications. Droplets of condensing degradation products are formed on the surface of the breakdown zone. Very little solidification is observed upon the introduced electrical breakdown in this elastomer, and most importantly, there is no solidified thread formation.

5 EDS

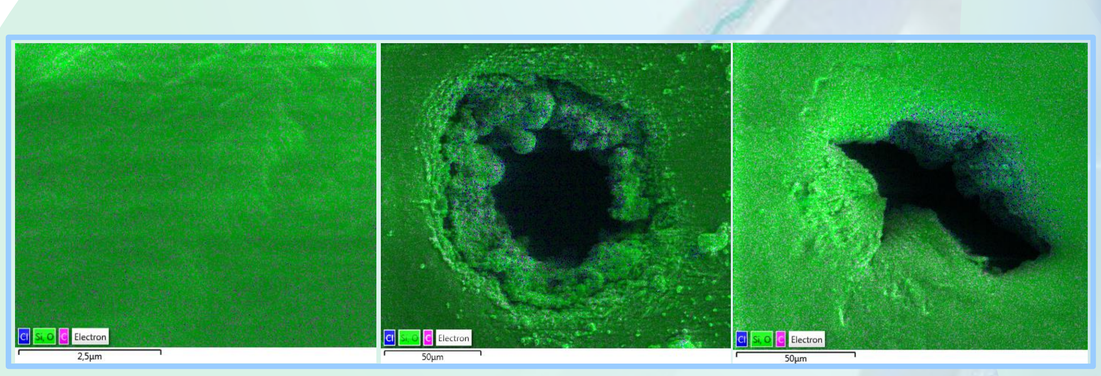

Figure 6. EDS mapping of Co-2 elastomer surface where Cl is uniformly distributed (left), breakdown zones for Co-1 (middle) and Co-2 (right). The material in the vicinity of the void contains excess of Cl (blue color), which support the hypothesis that silicon-containing substances have been evaporated off.

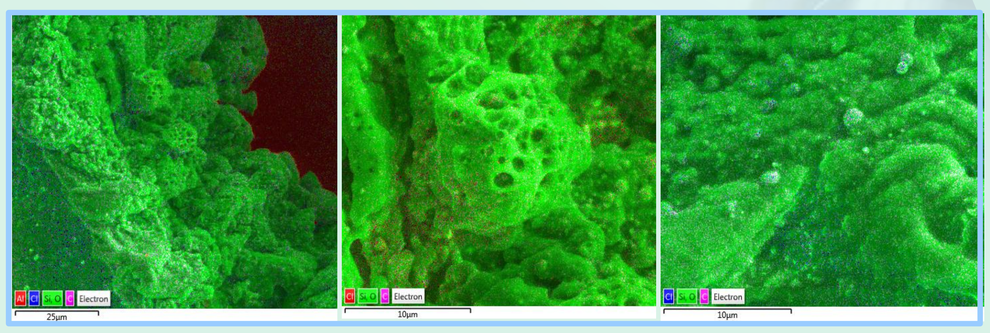

Figure 7. An increased concentration of Cl is recorded at the breakdown zones for the crosslinked copolymer Co-1.

6 Conclusion

It was shown the chemically very similar silicone elastomers broke down electrically in very different ways. These observations emphasize that the modification of the silicone backbone may open up for completely new possibilities for stabilizing the silicone elastomer electrically. In order to tailor the elastomers, more knowledge is needed but these copolymers pave the first path towards a better understanding of the complex connection between electrical and thermal stability. Minor changes in the polymer backbone structure result in changes in electrical breakdown patterns and understanding why is crucial for enabling design for extraordinarily stable elastomers and thus ultimately reliable dielectric elastomer based products.

Acknowledgments

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