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Simulation of Thermal Breakdown in a Multi-layered Stack of Dielectric Elastomers

Technical University of Denmark DTU

L. R. Christensen[1], O. Hassager[1], A. L. Skov[1]

1. Danish Polymer Centre, DTU Chemical Engineering, 2800 Lyngby, Denmark

INTRODUCTION: Dielectric Elastomers (DEs) consist of a thin elastomer film sandwiched between two compliant electrodes. When an external voltage is applied to the electrodes, electrostatic forces are created which cause the elastomer to decrease in thickness and since it is an flexible and incompressible material, it expands in the in-plane direction[1], as illustrated in Figure 1.

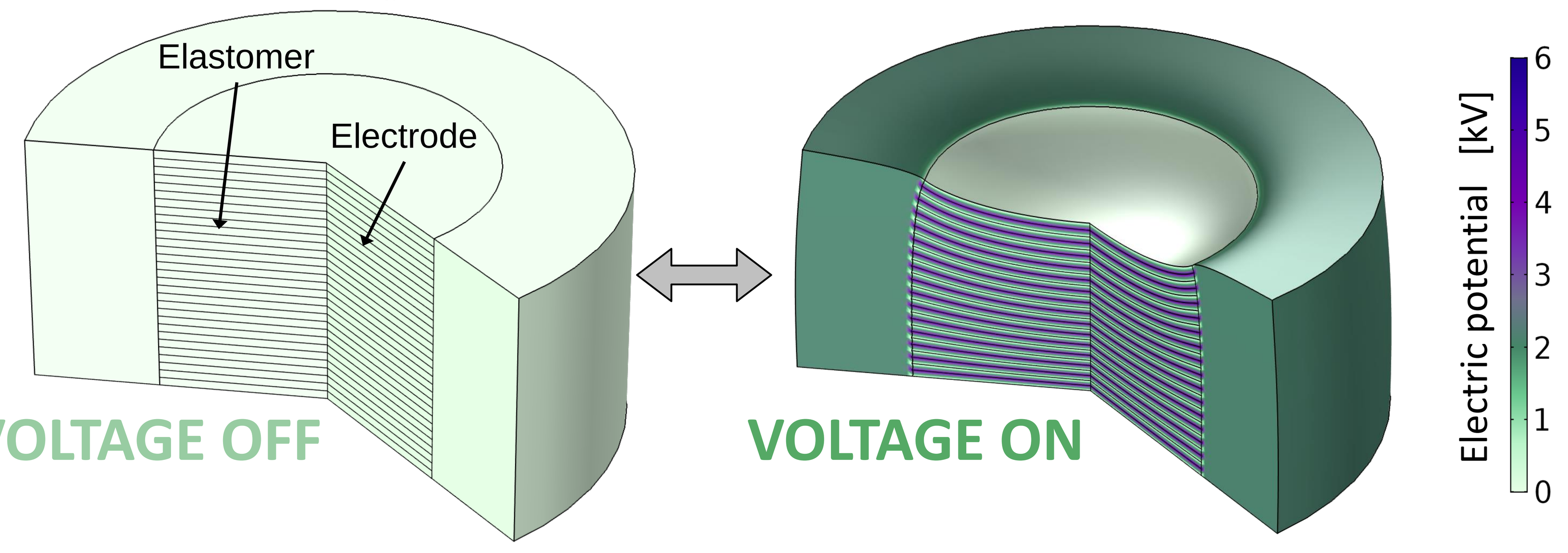

Figure 1. Working principle of dielectric elastomers.

Thermal breakdown occurs when the energy generated within the DE can no longer be balanced by the dissipated energy. The generated energy, Q_{gen}, is mainly from Joule heating:

$$Q_{gen} = I^2 R = \frac{V^2}{R} = E^2 N\, d\, \sigma(T) A_{cross}$$

COMPUTATIONAL METHODS: The setup is modeled in 2D axisymmetric by using the **Joule Heating** multiphysics interface to model the electro-thermal contribution, as well as the **Electromechanics** multiphysics interface to model the electro-mechanical contribution of the model. All simulations are **steady state** simulations. A stack of N elastomers are modeled, each layer having a thickness of 50 µm and a radius of 25 mm.

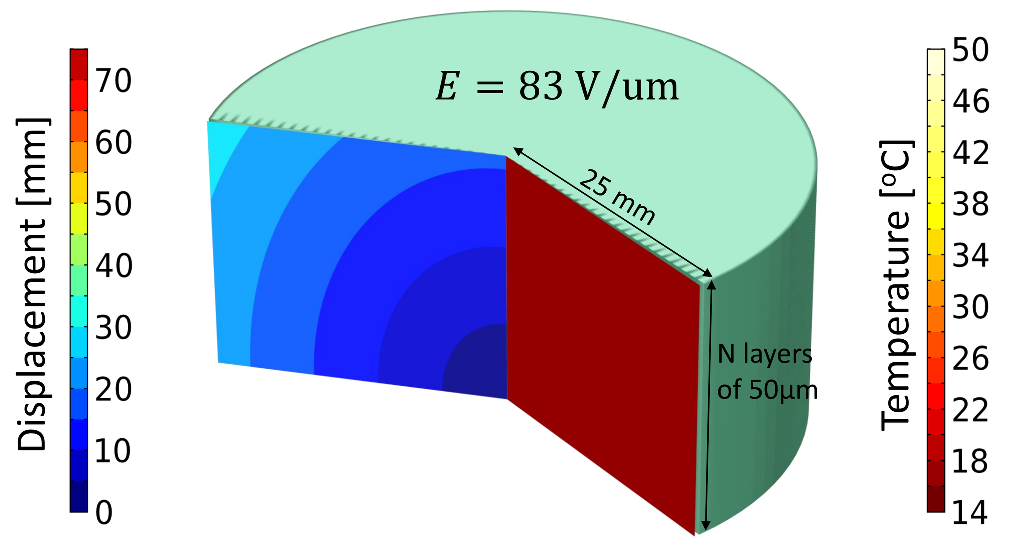

Figure 2. Base case simulation with N = 2000, T_0 = 15°C, and V_0 = 3.5 kV

The elastomer material is PDMS, with $k = 0.15$ W/K and $\epsilon_r = 2.8$. The electrical conductivity follows an Arrhenius expression on temperature[2], and the hyperelastic Yeoh model is used to model the elastomer material[3]. Three cases of heat transfer are examined:

- **Step 1**: Constant temperature on top and bottom, and thermal insulation on the curved surface.
- **Step 2**: Heat transfer on top and bottom, and thermal insulation on the curved surface.
- **Step 3**: Heat transfer on all surfaces.

The heat transfer functions are defined as follows:

$$h_{func}(T) = h_{const}\left((T - T_0)^2 \frac{1}{\mathrm{K}} + 1\right)^{1/8}$$

RESULTS: From the base case of $N = 2000$, $T_0 = 15^{\circ}$C, and $V_0 = 3.5$ kV a parameter study is conducted in order to study how these three parameters affect the point of thermal breakdown. Thermal breakdown is defined in the points where dT_{max}/dT_0, dT_{max}/dV_0, or dT_{max}/dN, respectively, approaches infinity.

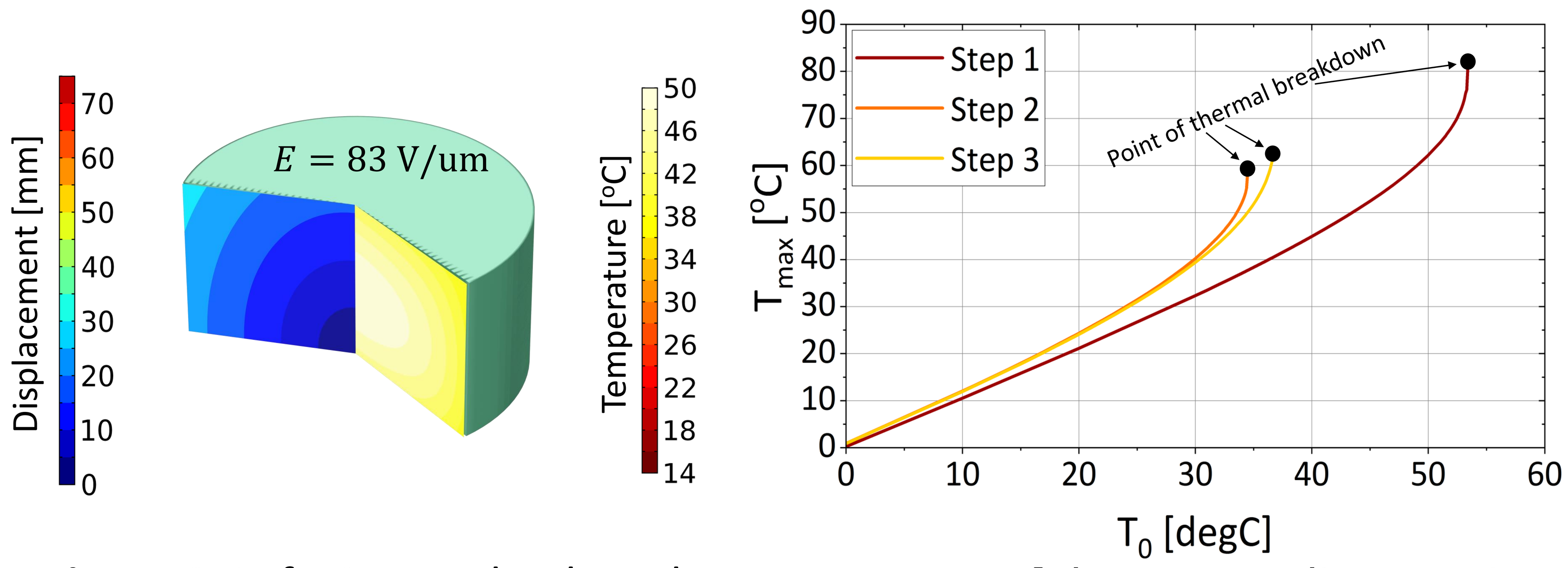

Figure 3. Left: 3D result when the temperature of the surroundings, T_0, is 34°C. Right: The effect on the T_{max} within the stack of DEs, when varying T_0.

From Figure 3 it can be seen that the point of thermal breakdown is highest in Step 1 when assuming constant temperature on the top and bottom of the stack and insulation on curved surface, due the fact that this resembles perfect heat transfer.

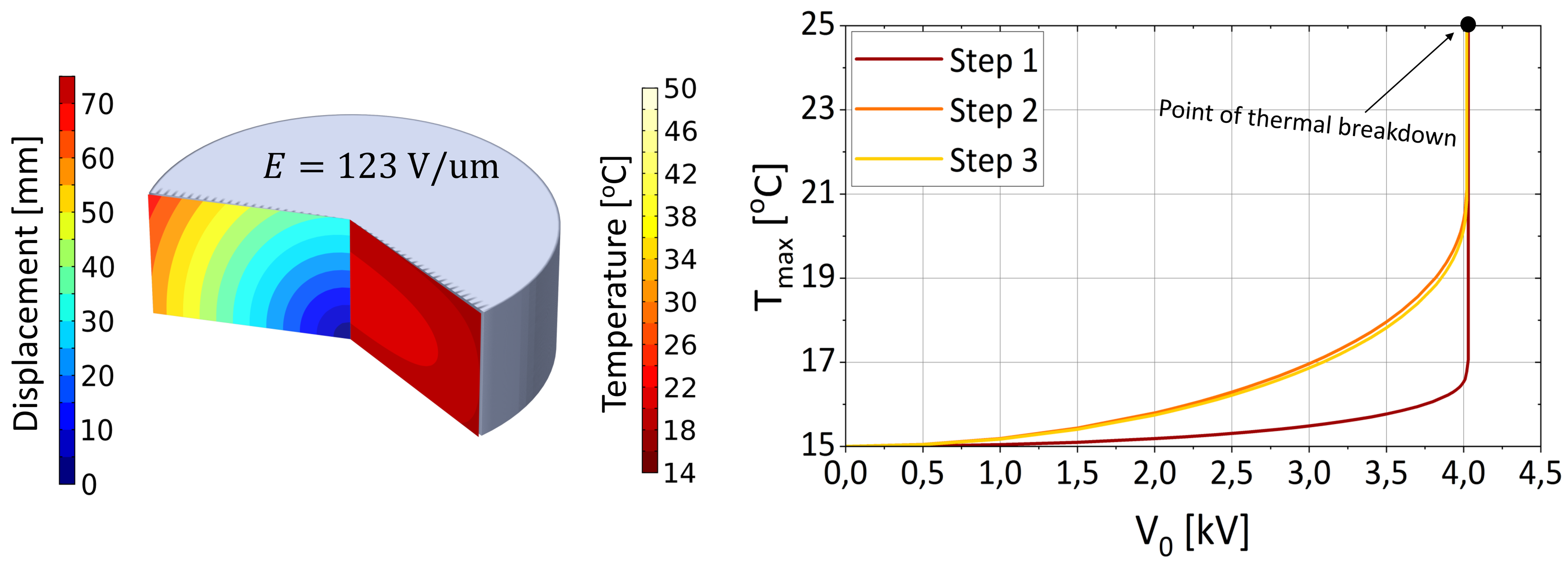

Figure 4. Left: 3D result when the applied electric potential, V_0, is 4 kV. Right: The effect on the T_{max} within the stack of DEs, when varying V_0.

From Figure 4 it seems that the point of breakdown when varying the applied electric field is not influenced by the heat transfer used. However, this might also indicate that the Yeoh model used is insufficient to model the compression.

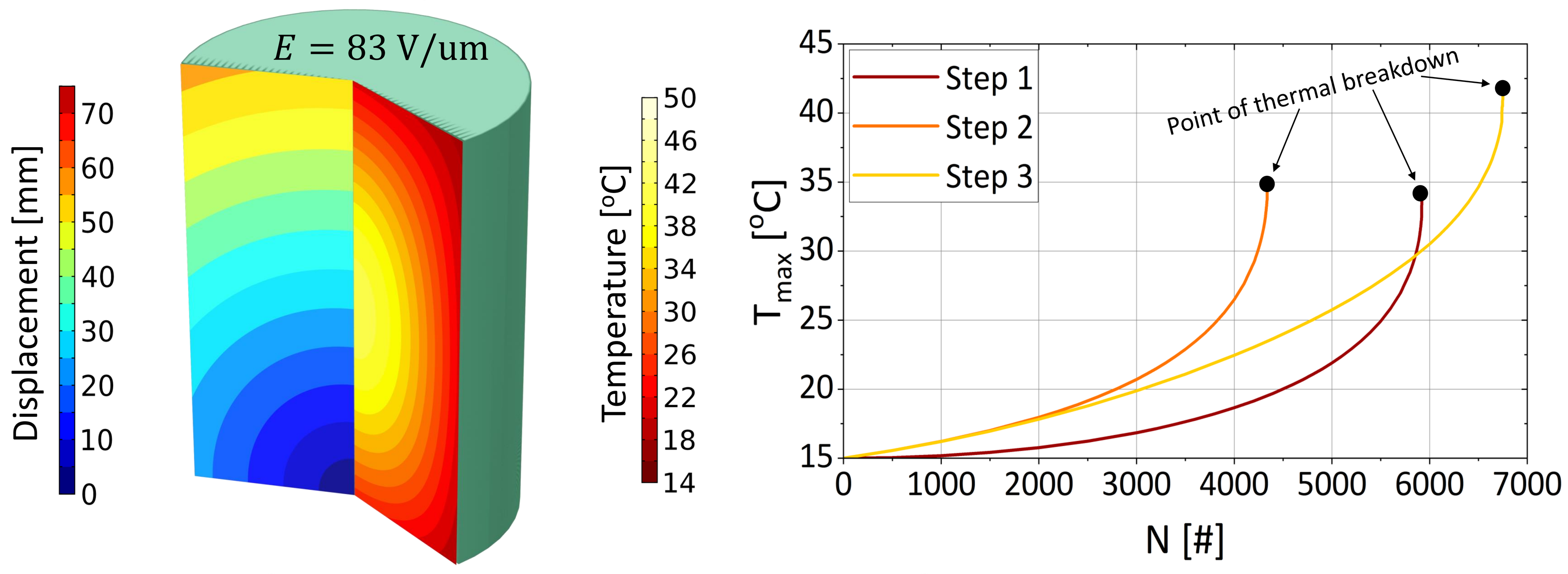

Figure 5. Left: 3D result when the number of layers in the stack, N, is 6751. Right: The effect on T_{max} within the stack of DEs, when varying N.

From Figure 5 it can be seen that when varying the number of layers, the case with the highest point of thermal breakdown is when having heat transfer on all surfaces.

REFERENCES:

1. Madsen et al. *The Current State of Silicone-Based Dielectric Elastomer Transducers*, Macromol. Rapid Comm.,37 (2016) 378-413.
2. Christensen et al. *Electro-Thermal model of Thermal Breakdown in Multilayered Dielectric Elastomers* (Under review).
3. Kuhring et al. *Finite Element Analysis of Multilayer DEAP Stack-Actuators,* Proc. SPIE, 9430 (2015).