Received: 14 July 2020 | Accepted: 23 November 2020

DOI: 10.1002/pamm.202000198

Experimental investigations of viscoelastic and ferroelectric heating in PZT–5H

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This contribution focuses on the separation of two effects causing a temperature change in experiments with electrically loaded ferroelectrics. These materials are often subjected to cyclic loading, where viscoelasticity prevails at lower electric fields, whereas dissipative heating by domain switching governs the heating above the coercive field. Different frequencies and load amplitudes are investigated experimentally.

1 Introduction

Ferroelectric materials are technically attractive ceramics because of their special properties. They are often used for actuators or sensors in the precision range or for the purpose of energy harvesting. Problems arise due to self–heating, caused by sufficiently high frequencies and electric fields, associated with changes in the material properties, thermal stresses and sometimes even phase transformations, whereupon the devices finally are inoperative. In low Curie temperature materials, such as barium titanate, even depolarization is possible. It is known that there are different effects leading to temperature change in ferroelectrics, i.e. dissipative effects and linear reversible effects [1–3]. The dissipative effects, observed in our experiments, should be classified as viscoelastic and ferroelectric heating. The latter is due to irreversible domain wall motion and has been investigated on the one hand numerically, based on a micropyhsical model, e.g. in [1,2], and on the other hand experimentally, e.g. in [3]. Since ferroelectric heating in undamaged samples only sets in at electrical loads equal to or larger than the coercive field, the viscoelastic effect can be isolated at electrical loads below the coercive field. Therefore, the temperature change in the material is determined by applying bipolar electrical loads to samples placed in a silicon oil bath and measuring the temperature of the oil surrounding the sample, see Fig. 1a. The experiments lasting for 3–4 hours with each sample have furthermore been recorded by a camera to investigate the possible onset of damage.

2 Results and discussion

In general, experiments shown in Figs. 2a - 2d are divided into two stages P_1 and P_2, where each one is assigned to an amplitude A_1 or A_2 of the bipolar electrical load applied to the samples. In the first stage P_1 the load is applied with an amplitude A_1 for a time $\bar{t}_i$, which is different for each sample i. In the second stage P_2, just the amplitude is changed, whereupon $A_2 > A_1$.

Fig. 2a shows the temperature change θ vs. time with $A_1 = 0.8\,E_\mathrm{C}$ and $A_2 = 1.2\,E_\mathrm{C}$ at 10 Hz. In the first stage the temperature shows for all samples a transient range, followed by a steady state. In the second stage P_2 the temperature rises sharply followed by a short stationary state in most samples, which is explicitly accentuated in Fig. 2b, closely followed by a decrease in temperature, which is attributed to the failure of the samples. The accentuated temperature curves of samples 2 and 5 in Fig. 2b, show the sharp rise in temperature at the beginning of the second stage, characterized by $t/\bar{t}_i \geq 1$, and a short stationary period being particulary pronounced in sample 5.

Fig. 2c shows results for loading with $A_1 = 0.9\,E_\mathrm{C}$ and $A_2 = 1.2\,E_\mathrm{C}$. In both specimens the temperature immediately increases, just as in Fig. 2a for $A_2 > E_\mathrm{C}$, followed by a decrease in temperature. Increasing the electric load to a level A_2, the procedure is repeated. A purely viscoelastic stage is not observed. Obviously, there is an onset of damage twice after the maxima and the coercivity of the material seems less than specified by the provider.

The temperature curves with the same loads as previously discussed in Figs. 2a and 2b, but a different frequency (1 Hz) are similar to the results of the latter two figures, apart from the magnitude, see Fig. 2d. The course of sample 8 is different from those of 6 and 7, because the sample is not broken into two parts, unlike the samples of specimens 6 and 7. The latter two were cracked completely during the experiment after 5310 s and 6120 s, respectively, as shown in Fig. 1b. It should be noted that in most cases the damage is just indicated at the surface of the sample, not exhibiting a complete rupture.

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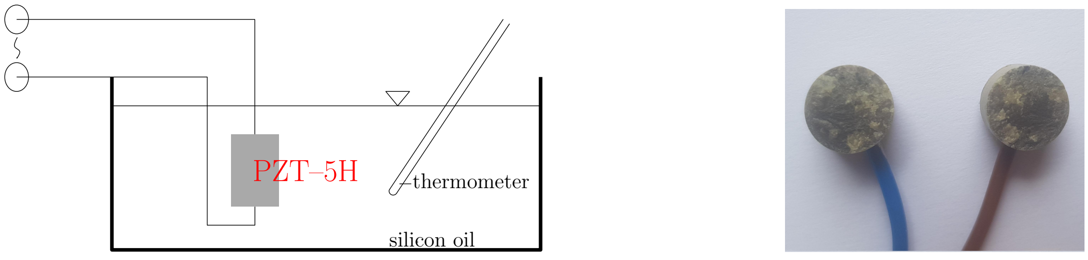
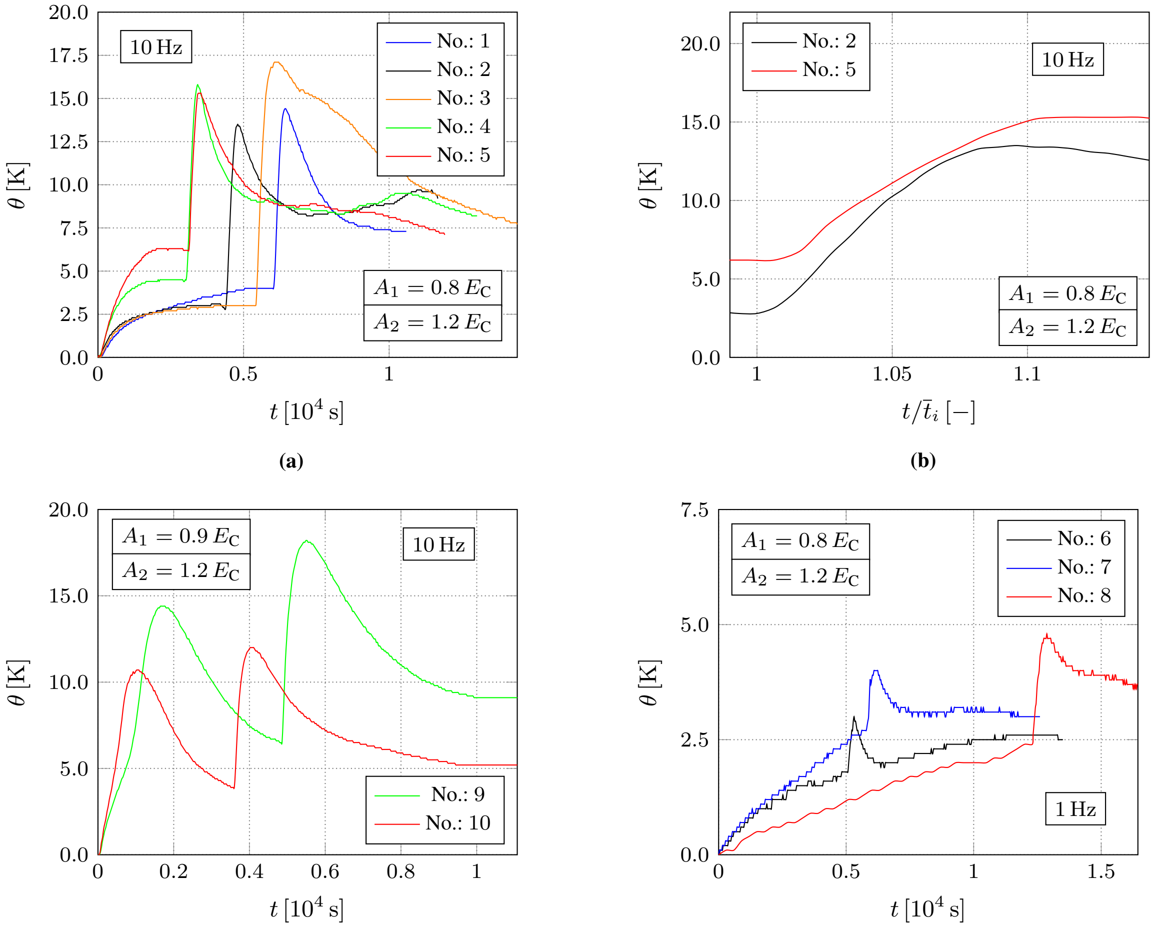
3 Conclusions

Both viscoelasticity and domain switching lead to dissipative heating in ferroelectrics, the latter effect dominating above the coercive field and typically amounting to 10–15 K. Viscoelasticity contributes with 3–6 K at 10 Hz and presumably 2–3 K at 1 Hz. After all, the investigated material appears to be heterogeneous and thus prone to cracking.



(a) **(b)**

Fig. 1: (a):experimental set–up; (b): fracture surfaces of a damaged sample



(a) **(b)** **(c)** **(d)**

Fig. 2: Experimental results of electrically loaded samples with amplitudes A_1, A_2 at 1 Hz or 10 Hz; (b) is an excerpt of (a)

Acknowledgements Open access funding enabled and organized by Projekt DEAL.

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