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New orientation effect in piezo-active 1–3-type composites

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HIGHLIGHTS

- Effect of the poling-axis orientation in 0–3 matrices of 1–0–3 composites is studied.
- Role of the elastic and piezoelectric anisotropy in the 0–3 matrix is highlighted.
- Two ferroelectric components with contrasting properties cause high performance.
- Maxima of three hydrostatic parameters are achieved at the same matrix microgeometry.

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ABSTRACT

This paper demonstrates the influence of the mutual orientation of the poling direction of single-crystal and ceramic components on the properties of 1–0–3 composites containing two ferroelectric components and a piezo-passive polymer. Effective properties to be considered are hydrostatic piezoelectric performance, anisotropy of squared figures of merit and electromechanical coupling factors. We demonstrate that the elastic and piezoelectric anisotropy of the 0–3 connectivity ferroelectric ceramic/polymer matrix with prolate inclusions leads to large hydrostatic piezoelectric coefficients (d_h^* and g_h^*) and squared figure of merit ($d_h^* g_h^*$) in a 1–0–3 0.67Pb($Mg_{1/3}Nb_{2/3}$)O_3–0.33PbTiO_3 single crystal/($Pb_{1-x}Ca_x$)TiO_3 ceramic/araldite composite with x = 0.20–0.25. In this type of composite values of maxg_h^* ~10^2 mV m/N and max($d_h^* g_h^*$) ~10^{-11} Pa^{-1} are achieved at specific volume-fraction and rotation-angle ranges due to a new orientation effect in the presence of a highly anisotropic 0–3 matrix. Such composites are of interest for sensor, actuator and energy-harvesting applications.

1. Introduction

Piezo-active composites are regarded as heterogeneous materials that consist of two components where at least one component exhibits piezoelectric properties. The piezoelectric component that is often selected is a poled ferroelectric ceramic with a high piezoelectric activity, dielectric permittivity and other characteristics which play an important role in determining the effective electromechanical properties of the composite [1–3]. Composites based on ferroelectrics are an important group of modern smart materials wherein the effective properties and their anisotropy can be varied and tailored in a wide range. These composite materials are of interest for piezoelectric sensor, actuator and hydrophone applications [1,4,5].

An important trend in the study of advanced piezo-active composites is the potential to modify their structure by introducing a third component that is able to further enhance the piezoelectric performance and hydrostatic piezoelectric response [6]. Among the composite systems with a high piezoelectric activity and/or sensitivity [7], of particular interest are composites based on domain-engineered relaxor-ferroelectric single crystals (SC) [8], e.g. $(1-z)$Pb($Mg_{1/3}Nb_{2/3}$)O_3 − zPbTiO_3 (PMN–zPT) or $(1-z)$Pb($Zn_{1/3}Nb_{2/3}$)O_3 − zPbTiO_3. Poling of these SCs in different directions leads to a *polarisation orientation effect* [7] in two-component SC/polymer composites with 1–3, 2–2 and 0–3 connectivities. This orientation effect depends not only on the connectivity of the composite system, but also on the electromechanical properties of the SC component. We note that polarisation orientation effects

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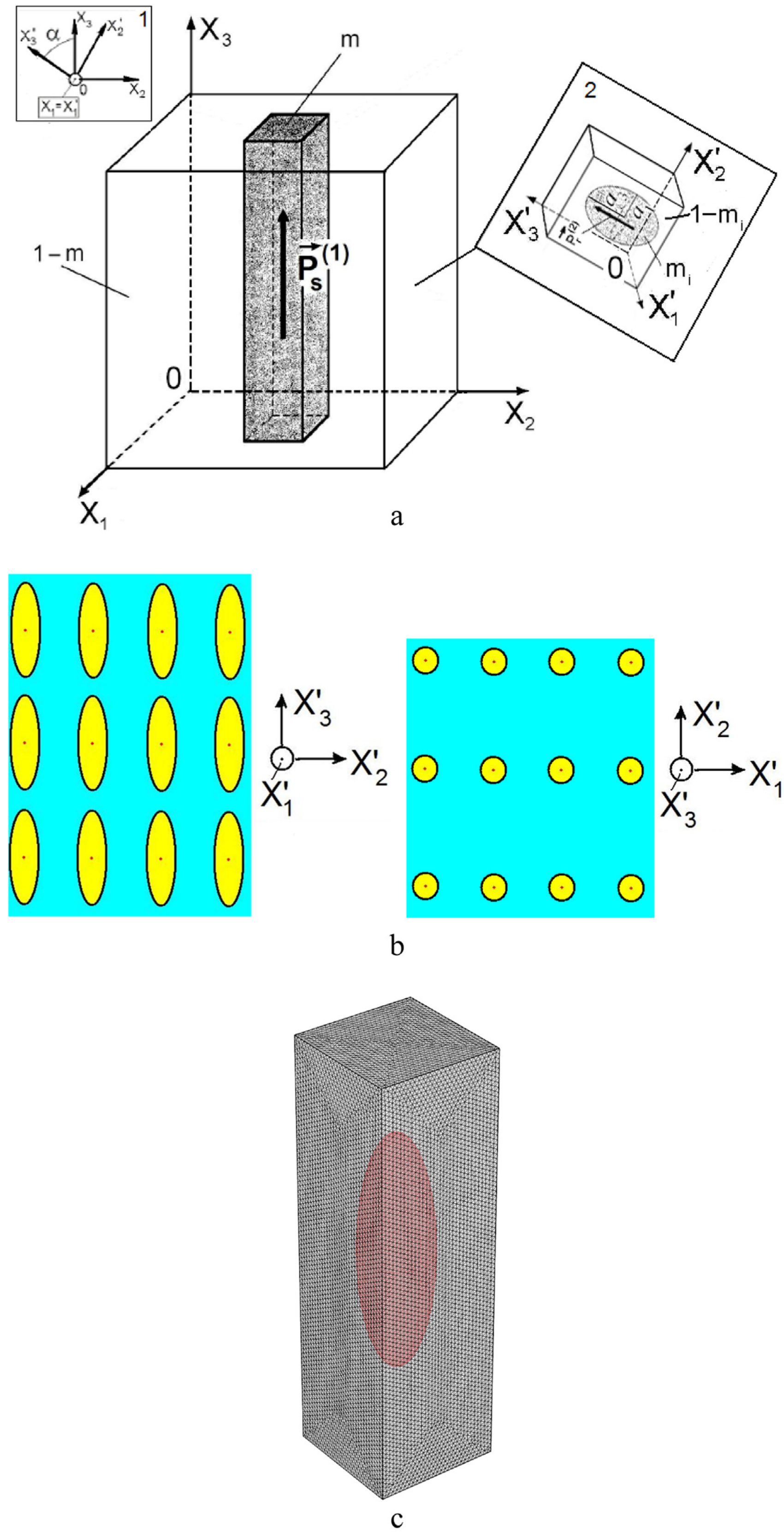

Fig. 1. Schematic of the 1–0–3 SC/ceramic/polymer composite (a), regular arrangement of spheroidal ceramic inclusions in the 0–3 matrix along the co-ordinate axes OX_k' (b) and mesh (c) used in finite element modeling for the 0–3 matrix. m and $1 - m$ are volume fractions of the SC and surrounding 0–3 matrix, respectively. Rotation of co-ordinate axes $(X_1'X_2'X_3') \rightarrow (X_1X_2X_3)$ is shown in inset 1 of Fig. 1,a, the 0–3 matrix is shown in inset 2 of Fig. 1,a. In the 0–3 matrix, m_i and $1 - m_i$ are volume fractions of the ceramic and polymer, respectively.