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Analysis of porosity influence on the effective moduli of ceramic matrix PZT composite based on the simplified finite element model

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To improve the efficiency of piezoelectric materials, composites based on piezoceramics are being actively created during the last years. So, to improve the mechanical properties, more rigid crystallites can be added to piezoceramics at the sintering stage and a piezoceramic – crystallite composite can be obtained. In reality, such a composite is three-phase, consisting of a piezoceramic matrix, elastic inclusions and pores, mostly located at the boundaries between piezoceramics and inclusions. The total porosity in ceramic-matrix composites can be both small and large enough. In this regard, when designing such composites, it is desirable to take porosity into account either as the third phase, or as the boundary of a loose contact of the main phases.

This paper considers the problem of determining the full set of effective moduli of granular piezocomposites, taking into account both the distributed microporosity in the ceramic matrix and the mesoporosity on some of the contact boundaries of elastic granules with piezoceramics, i.e. taking into account pores comparable in size to the size of inclusions. The homogenization problems were solved using the effective moduli method of the mechanics of composites. All stages of modelling and computing were implemented in the ANSYS finite element package.

A cube uniformly divided into cubic cells was considered as a representative volume element. Each cell consisted of finite elements in the form of rectangular parallelepipeds with the properties of dense PZT ceramics, material of elastic inclusions or pores. Some cells consisted of eight finite elements, with only the main cubic elements provided with properties of inclusions by random number sensor (painted in turquoise in Fig. 1 and 2). The finite elements adjacent to the faces with the elements - inclusions, by a random number sensor were endowed with the properties of pores (painted in purple in Fig. 1 and 2). The remaining elements of the structure (painted in red in Fig. 1 and 2) had the material properties of the PZT ceramic matrix. The choice of the relative sizes of inclusions and pores, as well as the number of elements of inclusions and pores, was determined on the basis of the specified volume concentrations of inclusions and pores.

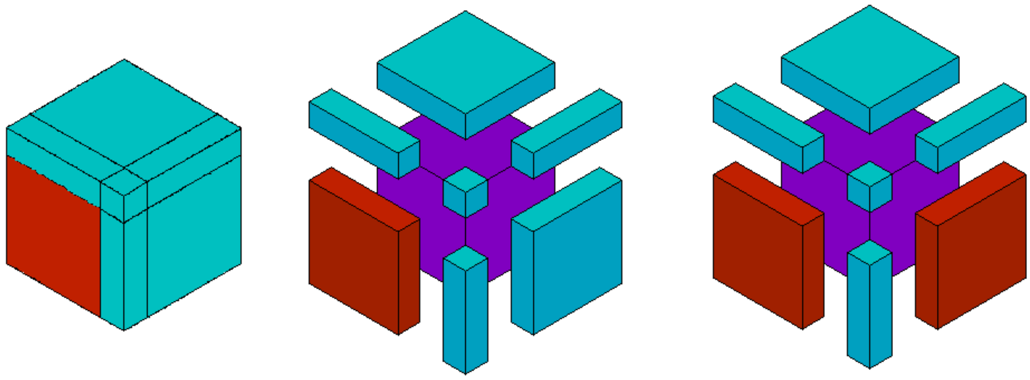

Figure 1. Example of the composite unit cell.

Figure 1 shows an example of a single ceramic matrix composite cell with inclusion and pores. The cell itself is shown on the left, the disassembled cell with one pore in the center, the disassembled cell with two pores on the right.

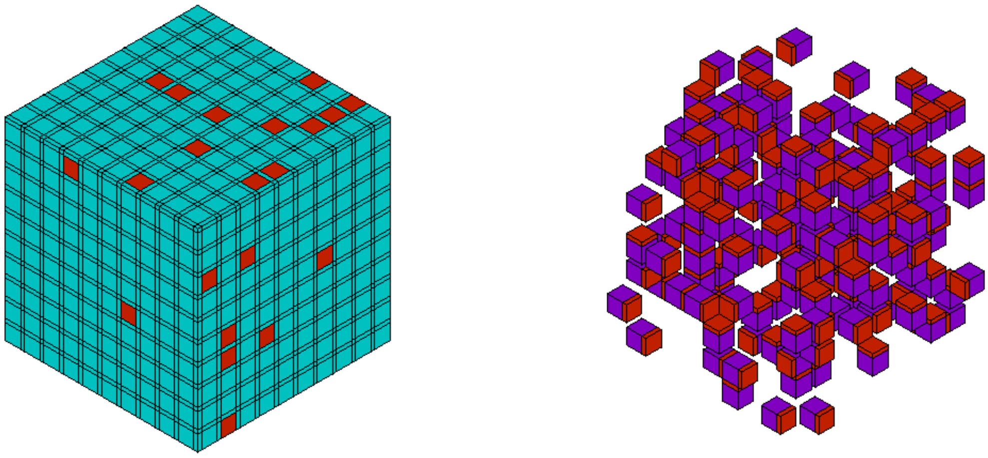

Figure 2. Example of a representative volume of the composite.

Figure 2 shows an example of a representative volume of the composite in which each inclusion has one pore nearby. The entire representative volume is shown on the left, and the elements with properties of inclusions and pores are shown on the right.

The described technique of constructing representative volumes was applied to composites with mesoporosity. The microporosity accounting was carried out in two stages. At the first stage, structures of representative volumes of microporous PZT ceramic material were built using a similar technology without elastic inclusions and its effective moduli were determined. At the second stage, the ceramic-matrix composite with micro- and mesoporosity was studied as a three-phase: the first phase were piezoelectric ceramics with effective moduli of the microporous material found at the first stage, the second phase were elastic inclusions, and the third phase were mesopores.

As an example, calculations of effective moduli of composites consisting of a piezoceramic matrix of PCR-1 and with inclusions of α-corundum were carried out. The analysis of effective moduli was carried out depending on the proportion of inclusions and the presence or absence of micro- and mesoporosity. The resulting dependences of the effective moduli on the content of inclusions and pores were as expected. Since the inclusions were more rigid than piezoceramics, the effective moduli of stiffness increased with the increase in the proportion of inclusions. In addition, since the inclusions were absolutely elastic with low dielectric permittivities, the effective piezomoduli and dielectric permittivities decreased in absolute value with an increase in the fraction of inclusions. The accounting of the porosity reduced the effective stiffness as well as piezomoduli and dielectric constants. At the same time, mesoporosity had a more significant effect compared to micro porosity, since, in the presence of mesopores, the boundaries of incomplete fit of inclusions with a ceramic matrix were also taken into account. The results obtained allow to estimate the effective moduli of ceramic matrix piezocomposites for different proportions of inclusions, pores, and their sizes.

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