# Chapter 6
# Conclusions

*Science is an edged tool, with which men play like children, and cut their own fingers.*

A. Eddington

*As niche applications become more prevalent in the future, composites and displacement-amplifying techniques and materials will proliferate in a continuing effort to widen the force–displacement envelope of performance. These devices, too, will become smarter and smarter as the applications demand.*

G. H. Haertling

## 6.1 From Orientation Effects to a Large Anisotropy of Properties

Current challenges in the research field of composite materials are associated with the extension of the field of these materials from structural composites to functional and multifunctional composites [1] with the effective properties that depend on a large number of factors. The development of the composites for piezoelectric, pyroelectric and other functional applications can stimulate the manufacture of highly effective composites with tailored and predictable performance. In this context the orientation effects discussed in the present monograph broaden our outlook when studying the well-known *composition—structure—properties* relations [2, 3] in the piezo-active composites. Examination of the orientation effects has to lead to an improvement of the performance of the piezo-active composites, the anisotropy of their piezoelectric coefficients and ECFs, the hydrostatic piezoelectric response, etc. It is obvious that fundamental links between the domain orientations and electromechanical properties in modern relaxor-ferroelectric SCs with high piezoelectric activity rep-

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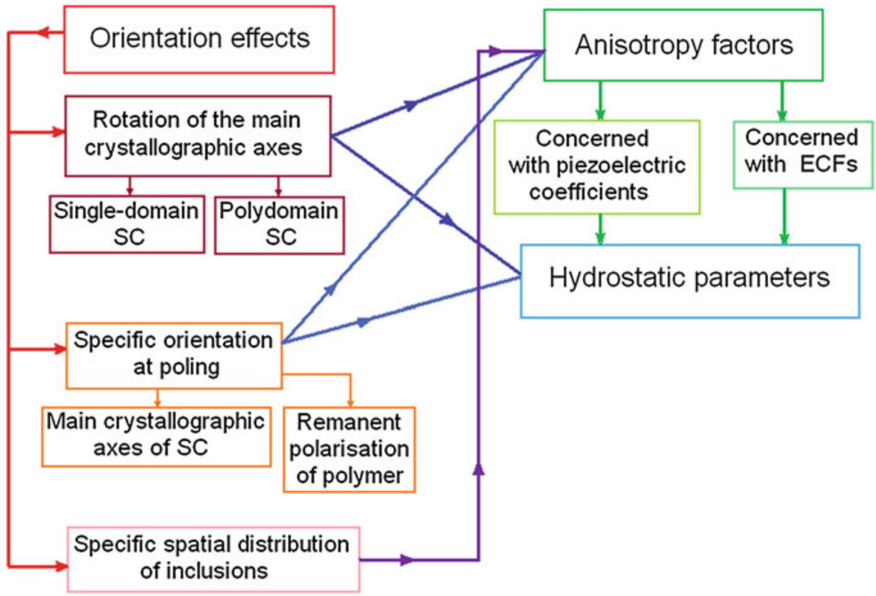


**Fig. 6.1** Interconnections between the orientation effects, anisotropy factors and hydrostatic parameters in composites based on ferroelectric SCs

resent a considerable opportunity for improving the performance of the SC/polymer and SC/porous polymer composites. We have obtained new "freedom degrees" that enable us to have control over the piezoelectric performance and anisotropy of the novel composites. The orientation effects in the FC-based composites studied in the monograph are less pronounced, but are also important and should be taken into account when predicting performance and for future applications.

In Chap. 3–5 we have considered three main examples of the connectivity patterns, namely, 2–2, 1–3 and 0–3, and on their basis we have additionally analysed some modified composite architectures, for instance, 1–3–0 with a porous polymer matrix. As follows from our results, in the composites with porous polymers there are more opportunities to vary the piezoelectric coefficients, anisotropy factors and hydrostatic parameters in wide ranges. The additional "freedom degrees" associated with the porous structure (features of microgeometry, volume fraction, spatial distribution of pores, etc.) in the composite systems studied are of value for a variety of piezotechnical, hydroacoustic and other applications.

We represent the main trends in the current study by means of two diagrams (Figs. 6.1 and 6.2). These diagrams enable us to emphasise the role of various factors and interconnections which are concerned with the orientation effects, microgeometric and anisotropic characteristics of the composites discussed. It is clear that the issue of the large piezoelectric anisotropy, discussed mainly in papers on the $PbTiO_3$-type FCs [4–6] in the 1980–1990s, can be solved in different ways, for

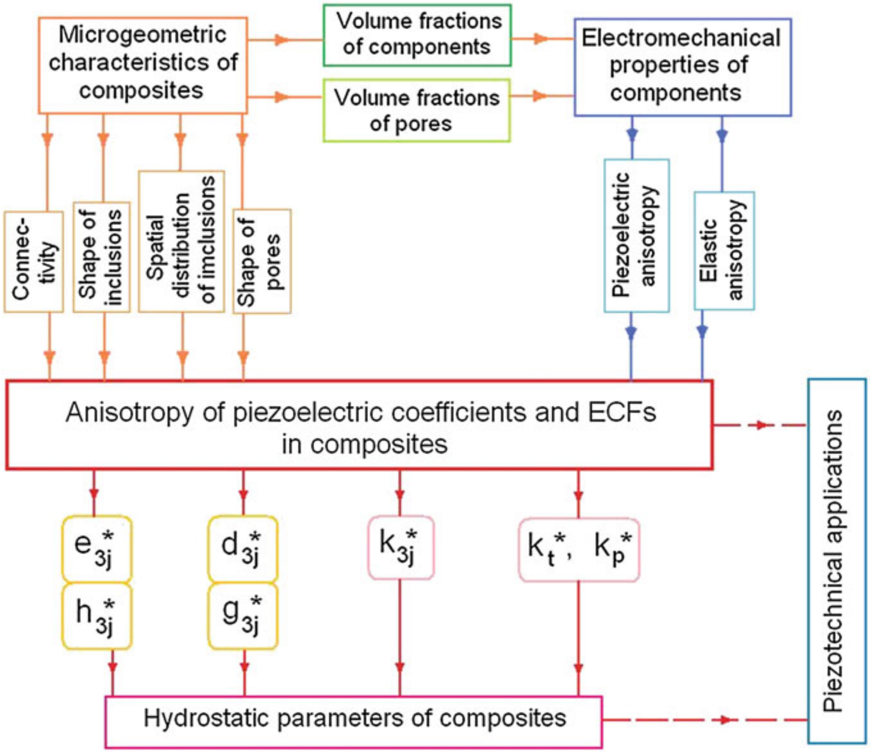


**Fig. 6.2** *Microgeometry—properties—anisotropy* relations in piezo-active composites

instance, by creating highly anisotropic composites containing a SC component with considerable piezoelectric activity and a porous polymer matrix; along with taking into account features of the orientation dependence of the electromechanical properties of the SC component and forming a specific porous structure in the polymer medium. Solving this problem in the composite (not FC) field, we find new important relations between microgeometry and electromechanical properties of the composite (Fig. 6.2), and these findings are to be taken into consideration in manufacturing new composites and further applications.

Knowledge of the aforementioned interconnections (see Figs. 6.1 and 6.2) can lead to an improvement of the piezoelectric performance and anisotropy factors of the composites based on ferroelectrics. Undoubtedly, the diagrams shown in Figs. 6.1 and 6.2 may be reinforced in future studies devoted to the advanced composites based on ferroelectrics or related materials. It is clear, that due to many additional microgeometric, technological and other factors, it is impossible to draw a universal picture of methods of improving the performance of the piezo-active composite or controlling its anisotropy factors even in a restricted range. In this case we would like to finish with the following words by P. Valéry: “Science means simply the aggregate of all the recipes that are always successful. The rest is literature”.

## References

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