UNIVERSITÀ DEGLI STUDI DELL'AQUILA
M&MOCS
International Research Center on
MATHEMATICS AND MECHANICS
OF COMPLEX SYSTEMS

OPINION

about PhD thesis of Mojtaba Biglar on
"Strain state in neighbourhood of defects in piezo-electric ceramic material"

commissioned by

the Dean of the Faculty of Mechanical Engineering and Aeronautics
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Overall job assessment

This PhD dissertation presents a micromechanical analysis of piezoelectric actuator by using boundary element method. More particularly it has been addressed the study of the influence of defects created during manufacturing process on the strain-state in neighbourhood of defects in piezo-electric ceramic material.

The failures and defects of piezoelectric ceramics are considered to be the main cause for damage of ceramic transducers when they convert mechanical energy directly into electrical energy, and vice versa, with high speed and force. The knowledge of crack initiation conditions and suitable selection of ceramic manufacturing process conditions are one of the most important problems considered by many authors to assure the long actuator life.

One of the most used technique to study the damage conditions of piezoelectric ceramic is based on the analysis by boundary element method which is a numerical method of solving linear partial differential equations formulated as integral equations. In is important that the boundary element method requires only to mesh boundary of the ceramic grains without introducing calculation parameters inside of the grain. In this case the size of algebraic equations is considerably smaller than when using finite element method. However to apply the boundary element method for studying the crack initiation in piezoelectric actuator it is necessary to recognize the structure of ceramic material. For this reason the PhD student prepared the barium titanate powder using solid-state technique. The microstructure of prepared pellets and beams is evaluated by means of scanning electron microscopy (SEM). To discretize boundaries of grains based on the SEM microstructures the comprehensive algorithm is developed based on image processing methods, which is able to provide exact information about grains boundary.

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To found accurate information of crack initiation and its evolution in grain boundary of micro-aggregate the Author suppose some important assumptions: first of all he assumes that all the nodes pairs are in undamaged areas and that equilibrium and displacements compatibility are verified. The second assumption is that when the traction exceeds the ultimate value, the micro-crack starts to initiate and then the micro-aggregate is weakening. A frictional law is considered to investigate separation, sliding or sticking between micro-crack surfaces both in compression and tension modes. The transducers exhibit piezoelectric properties, so in order to generate the numerical algorithm for them the Author assumed the equality of electric displacement and potential on upper and lower of crack surfaces. For implementing the micro-mechanical analysis of intergranular crack degradation and evaluation in polycrystalline aggregate and representative volume element of multilayer actuator the Author developed an incremental-international adaptive algorithm. The effect of such parameters as i) grain size and grain morphology, ii) piezoelectric effect coefficient, iii) pre-deformation of cracks, iv) resistivity and friction coefficient of interfaces on the micro-fracture patterns of the piezoelectric polycrystalline material is investigated and discussed. The presented results show the high efficiency of developed micromechanical model in prediction of crack propagation in piezoelectric actuator.

The PhD thesis contains eight chapters, a list of references and an appendix.
The thesis is preceded by an introduction. In Chapter 1 the Author, based on the literature, provide the basic information about piezoelectric materials and manufacturing processes of piezoelectric ceramic. Furthermore, some works concerned the boundary element applications and multiscale modelling are discussed. Second Chapter contains the motivation and scientific thesis of PhD dissertation. Chapter 3 presents the methods and basic formulations of boundary element method, and the results of stress variation in cracked rectangular plate with and without inclusion. Chapter 4 deals with basic formulations of multiscale modelling with examples of application of boundary element method at macro and micro scale. In this chapter the procedures which were applied to obtain final model from SEM image are also described. In fifth chapter, the averaging theory is utilized to obtain information from micro-scale for prediction of crack initiation in RVE of multilayer actuator. In this section some numerical examples both on polycrystalline materials and multilayer actuator are presented to found the efficiency of used method. Parameters characterising the extent of material sintering, SEM microstructures and electric properties of the fabricated pellets are presented and discussed in Chapter 6. The dilatometric curve is executed using the high temperature dilatometer in order to determine at which temperature barium titanate pellets and beams should be sintered to receive full dense sinters. The values of parameters characterizing the extent of material sintering i.e. the apparent porosity, the apparent density, the water absorbability are presented. In Chapter 7 some numerical examples are provided in order to show the performance of generated BEM codes taking into account cohesive law and frictional contact. The obtained results confirm the effectiveness of developed numerical programs in prediction of electrical and mechanical properties multilayer piezoelectric actuator. Chapter 8 contains conclusions and suggestions to future investigations. In Appendix section those parts of numerical algorithms designed in MATLAB to solve the problem of grain boundary formulation and boundary element method are explained.

Strengths of dissertation

The presented work is complete and ranges from literature review, synthesis of barium titanate perovskite material by solid state method, fabrication of barium titanate granulate on spray drier, preparation of pellets and beams by uniaxial and isostatic pressing methods, optimization of sinters microstructure, the problem of metallic layers deposition, and finally preparation of stacked-disk multilayer actuator. PhD student has determined all those properties of barium titanate material at each stage of its fabrication (powder, granulate, sintered material) which are influencing on its application for the stacked-disk multilayer actuator.

The methodology used in the numerical part of dissertation is considered appropriate. The following tasks performed by the Author deserve special mention:

1. Developing a comprehensive algorithm based on image processing technique, which is able to provide exact information about grains boundaries.
2. Generation an adaptive algorithm to make a linear system of equation via considering boundary element coefficients, grain boundary micro-mechanical model and transgranular opening or micro-crack.
3. Design an incremental-iterational system of loading for establishing convergence for iterations in the every increment.

Critical remarks

The experimental research conducted within the framework of PhD thesis was very well planned and executed, which gives evidence of high expertise of PhD student in this field. However, I have three questions and critical comments to the experimental part of PhD dissertation:

1. In order to synthesize the barium titanate powder, PhD student has chosen the solid state method, which requires application of the high calcination temperature that can lead to very large and non-uniform grain sizes. What was the reason of selection of this synthesis method?
2. Although the obtained results in the experimental part are carefully described and analysed, in my opinion the outcomes referring to the stage of pellets sintering presented in Tables 6.1 and 6.2 should be enriched by results concerning porosity, which is quite important during the microstructure modelling of material.
3. PhD student rightly noticed that the grain size of piezoelectric sinter strongly influences the dielectric constant. Therefore, he improved the microstructure of sinter, in the direction of the smaller grains so getting, by the thermal treatment of green pellets according to the special designed sintering curves. The other possibility of this problem solving is also mechanical activation of powder to obtain smaller grain size and sintering at lower temperature. Why did not PhD student apply such solution in his approach?

Considering the numerical part of the dissertation, in my opinion, some block diagrams of the developed algorithms will improve the clarity of the communication.

Formal comments

In the thesis there are some misprints, for example, on page 22 "incremental-international" should be, in my opinion, "incremental-iterational". In many cases the used notations and conventions should be

used consistently, for example Author uses in the text phrase "micromechanical model" (e.g., on page 22) and "micro-mechanical model" (e.g., on page 23). The meaning of "kicked crack" (page 31) is unclear. The meaning of the phrase "discrediting" (page 27) is also unclear. In Fig. 7.10 the numbers and axis captions are too small. The indicated minor mistakes and inaccuracies do not affect the high substantive assessment of the dissertation.

Final remarks

Summarizing, the PhD dissertation represents a high level scientific work. This dissertation is a valuable contribution to the analysis of the influence of defects created during manufacturing process on the strain-state in neighbourhood of defects in piezo-electric ceramic material. The dissertation demonstrates that Author understands well-enough the relevant literature in the field of numerical and experimental analysis of cracks in piezoelectric ceramic. The experiments are generally well-arranged and used methods are correct. The quality of written text is acceptable. The high scientific level of the dissertation and the developed complex numerical algorithms confirm the ability of the Author to analyse and solving complicated scientific problems. The presented doctoral thesis titled "Strain state in neighbourhood of defects in piezo-electric ceramic material " meets the requirements of the Law on Degrees and Scientific Title, and I request that it can be admitted to the public defence.

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