# a. ABSTRACT

The habilitation thesis presents the scientific achievements of the author, undertaken in the period of 2001 and 2015 in the field of optical methods in experimental mechanics of solids. During the above mentioned period, the research and professional interests of the author of this thesis, have been focused mainly on implementation of new applications and improving of experimental techniques in mechanics of materials and other connected fields. The researches include near experimental techniques and also numerous validations by analytical and numerical (Finite Element) methods.

Beginning with the PhD thesis (1996-2000) and continuing more than one decade the research and also the didactic activities required to apply and deeply understand the numerous experimental techniques such as: strain gages, photoelasticity, geometric moiré, interferometric moiré, electronic speckle pattern interferometry (ESPI), optical metrology, digital image correlation (DIC), thermoelasticity, non-destructive testing (NDT) and microindentation. All these methods are interdisciplinary and interact with topics like physics, optics, image processing, materials, fabrication processes, etc. The possibilities of direct measure are nowadays extremely rare and to measure implies besides manipulation of complex measuring systems, understanding of measurand and limit of application of measurement method.

Stress analysis has been considered for some time as a distinct professional branch of engineering, the main objective to determine and improve the mechanical strength of elements, structures and machines. Experimental stress analysis strives to achieve these aims by experimental means. In the investigation of problems of mechanical strength, many factors make the experimental approach indispensable, and often the only means of access. In addition to this, theoretical considerations are usually based on simplifying assumptions which imply certain deviations from reality, and it can be established only by experimentation whether such idealization do not produce an undue distortion of the problem. Using experimental stress analysis is required especially if the analysis is done under real service conditions, where thre are all the influential factors such properties of the employed materials, the methods of manufacture and the operation conditions. A special place among the experimental techniques is occupied by optical methods. Among their numerous possible applications, they can help the researcher to characterize the materials' behaviour, to give access to the time-evolution of fields of data at different scales and maybe, the most important advantage, they are non-contact and provide full-field data that are naturally suitable for direct comparison with numerical solutions.

The habilitation thesis is structured in three sections, one presents the main achievements in the field of optical methods of experimental mechanics, and the second one provides aspects regarding didactic skills and professional achievements and the last one sketches the proposed future scientific, professional and academic development plan.

The first section, *Achievements and development plan*, details briefly the research directions and mentions the main articles indexed in Web of Science, Scopus and Google Scholar databases. The author's research activities can be fitted in the following four main fields: experimental methods in solid mechanics, material testing and characterization, structural analysis and numerical simulation of MEMS and biomedical engineering. Only the contributions connected with the field of optical methods are presented in the thesis eventhough the other research directions have also relevant articles and achievements.

Optical methods of experimental mechanics of solids described in this thesis are the most applied in the research and industry. The thesis presents in the first chapter 2.1 the general context of experimental techniques, trends and future perspectives.

Second chapter 2.2 is dedicated to *photoeleasticity* and presents besides a short introduction of the technique a study of flexible shells of revolution by three dimensional photoelasticity. Application of measurement method to thin wall structures was less presented in the literature, an important advantage of the method is displaying the full field stress distribution that can be directly compared with numerical simulations. Main results and limitations of the measurement method are presented through studies of bellows subjected to axial loading and influence of the model weight in case of photoelastic analysis.

Chapter 2.3 is dedicated to optical method of geometric moiré and its particular set-up called *shadow moiré*. The author applied the method to solve a research contract for young researchers (type AT - CNCSIS) which has investigated large deformations of pressurized membranes by analytical, numerical and experimental methods. The sensitivity of standard shadow moiré method used for contour determination of the objects is relatively reduced and it is mainly influenced by the pitch of the master grid. The chapter presents application of the phase shifting procedure that brings a significant improvement of the measurement precision and sensitivity, the method's accuracy comparatively with the classical shadow moiré will increase up to ten times. Successful implementation of the methods led also to solution of torsion problem of bars with arbitrarily cross sections using membrane analogy.

Chapter 2.4 presents the method of *electronic speckle pattern interferometry* (ESPI). ESPI is an optical measuring technique that allows rapid and highly accurate measurement of deformations. In comparison with other techniques for strain measurement or calculation, the ESPI enjoys the advantages of being non-contact, full-field, has a high spatial resolution, high sensitivity, delivers accurate displacement data and does not require any calibration or costly surface preparation. The method has been employed by the author over many years spent mostly abroad, starting within a Marie-Curie research fellowship (2001-2003) in a German company that produces optical measurements systems based on ESPI and followed at Chemnitz University of Technology, Germany, Department of Experimental Mechanics (2005-2006) as an Alexander von Humboldt Foundation fellow. Since then there were published one book and several papers in the proceedings of international conferences or journals, among them being the most cited paper of the author. As the main contributions there are presented applications of ESPI in material characterization namely characterization of thermal expansion coefficient of isotropic and anisotropic materials and investigation of non-linear springback for high strength steel sheets. Both studies provide practical importance and contain new measurement concepts and methodologies.

Chapter 2.5 presents an optical method that has had a major impact in the field of mechanics of solids and structures and it is still undergoing very interesting developments, called *digital image correlation* (DIC). A specific advantage of this tool is that it exploits numerical images that are usually acquired by optical means. Comparatively with other optical techniques to measure displacements where light modulation produces fringe patterns and these patterns contain phase information that can be decoded, in DIC displacements there are directly obtained from point trajectories. The chapter analyses the concepts of two and three-dimensional DIC and presents numerous applications: measurement of flexural modulus of wood beams, materials curves and constants determination, investigation of polymers mechanical behaviour and with insights of the non-uniform strain behaviour of these materials in the yield and post-yield regimes, measurement methodology and accuracy of coefficient of thermal expansion determination using a 3D digital image correlation system for plastics and analysis of thermal sensors at micro and micro-scale.

Chapter 2.6 presents the results achieved within a research grant (Marie-Curie European Reintegration Grant FP6) entitled *MATLAB Scientific Toolbox for Strain-Stress Analysis.* To complete a complex strain-stress investigation using optical methods sophisticated equipment controlled by dedicated computer software is needed. Interaction of the researcher in the measuring process or data manipulation is in most cases restricted and one low cost solution but with high impact and flexibility was developing of a specialized MATLAB Scientific Toolbox to calculate full-field strain and stress distribution in components based on measured values given by different full-field optical methods. Beside the development of the toolbox the chapter presents some applications realized by the author: determination of stress concentration in a tensile specimen, determination of strain-stress values in a clamped plate loaded by a central concentrated force and determination of shear stresses in bars subjected to torsion using membrane analogy and shadow moiré.

Second section of the thesis briefly reviews the *didactic skills and professional achievements* underlining the following aspects: courses, seminars and laboratories that author is responsible for, student scientific activities of the Faculty of Mechanical Engineering, implication in professional competitions in the field of strength of materials, introduction of modern teaching methods and seminar software, participation as official referent for doctoral theses, achievements in institutional development and participation in committees and commissions in the interest of education.

Third section presents the plans for *future scientific and academic development*. In the scientific field the above mentioned research directions will continue but the effort will increase in those directions which facilitate publications in top research journals or access to the research projects. Among the plans concerning the didactic field there are: ensurance the continuity of the activities of publishing teaching materials for the students, introduction of optional courses, participation in multidisciplinary master programs, participation in international programs for the exchange of students, participation in projects with educational purpose and the last but not least attracting and mentoring of young people able and willing to pursue a doctoral stage and at the end an university career in the field of mechanics of materials.