UNIVERSITÀ DEGLI STUDI DI PALERMO

DEPARTMENT	Ingegneria
ACADEMIC YEAR	2020/2021
MASTER'S DEGREE (MSC)	BIOMEDICAL ENGINEERING
INTEGRATED COURSE	COMPUTATIONAL AND EXPERIMENTAL BIOMECHANICS OF PROSTHESIS AND ORTHOSES - INTEGRATED COURSE
CODE	20932
MODULES	Yes
NUMBER OF MODULES	2
SCIENTIFIC SECTOR(S)	ING-IND/14
HEAD PROFESSOR(S)	PITARRESI GIUSEPPE Professore Associato Univ. di PALERMO
OTHER PROFESSOR(S)	PITARRESI GIUSEPPE Professore Associato Univ. di PALERMO
CREDITS	9
PROPAEDEUTICAL SUBJECTS	
MUTUALIZATION	
YEAR	2
TERM (SEMESTER)	1° semester
ATTENDANCE	Not mandatory
EVALUATION	Out of 30
TEACHER OFFICE HOURS	**PITARRESI GIUSEPPE** Tuesday 14:00 15:30 Ufficio del docente (stanza O119) ubicato Edificio 8 primo piano plesso dell'Ex Istituto di Costruzione di Macchine (in fondo al corridoio centrale). Thursday 14:00 15:30 Ufficio del docente (stanza O119) ubicato Edificio 8 primo piano plesso dell'Ex Istituto di Costruzione di Macchine (in fondo al corridoio centrale).

DOCENTE: Prof. GIUSEPPE PITARRESI

PREREQUISITES	Basic knowledge of the below-listed subjects is advised: - Maths: Tensorial Calculus, Complex Numbers, Trigonometry; - Physics: basic notions of Electrical Circuits, Heat Transfer by conductivity and irradiance; - Statistics: basic knowledge of statistical treatment of data. Accuracy, Precision, and Bias, sensitivity and resolution of measurements; - Mechanics of Continuum: Stress and Strain Tensorial formulations and relationships, generalised Hook's law; - Mechanics of Materials: Ductile and brittle behaviour, Static and Fatigue strength behaviours.
LEARNING OUTCOMES	Knowledge and comprehension of: Students attending the course will gain knowledge on some fundamental approaches of Experimental Mechanics: 1) Use of universal testing machines for the mechanical characterization of materials for prosthesis and bio-materials; 2) Electrical strain gauges for the measurement of deformations and forces. Students will learn how to select and use electrical strain gauges for strain measurements on different materials, environments, and stress fields. In addition, they will learn how to exploit this technology for the correct conditioning and use of load cell and extensometer transducers. 3) IR Thermography. The principles of IR irradiation will be provided in order to use thermal cameras for the correct evaluation of an object temperature field. 4) Optical Methods: Digital Image Correlation: Students will learn about the principles of digital image correlation algorithms, the influence of optical and tele-camera parameters, and how to implement a DIC-2d experiment, interpreting results in terms of accuracy of measured displacements and strains. 5) Computational methods: At the end of the course, the student will have acquired knowledge and methodologies to solve biomechanics problems in an original way by numerical simulation methods. In particular, the student will acquire the ability to model the mechanical behavior of prostheses and orthoses. Ability to: From the theoretical knowledge and comprehension of the experimental techniques, and through the lab activities, students will gain the ability to: - choose and implement the correct experimental setup for biomaterial or prostheses material mechanical characterization; - use of electrical strain gauge setups for measuring strain fields or conditioning load cells and extensometers; - post-processing of strain gauge signals to obtain information on the stress/strain field, and material elastic/plastic/physical parameters; - operate IR Cameras and interpret correctly thermograms from different environmental conditions; - implement Digital Image Correlation setups at different geometric scales, being able to comprehend the influence of various tuning parameters (hardware and software) on the accuracy level of measured displacements and strains. - analyze, solve, and optimize problems typical of the prosthesis and orthosis design with the aid of numerical methods. - communicate with competence and language skills regarding complex numerical simulation problems for biomechanics. - deal with several problems concerning the use of numerical techniques for biomechanics.
ASSESSMENT METHODS	A unique exam will comprise the evaluation of both the Experimental Biomechanics module and the Computational Biomechanics module. A constant attendance of the course is mandatory to access the final examination. An individual written report on all lab and exercise activities must be prepared by each student singularly. This report will be subject to evaluation and will contribute to the final mark. Students who book for their examination must submit their report to the lecturer with at least one week advance from the day of the exam. The report can also be provided in an electronic version by email (pdf format). A typical exam will last between 40 and 60 minutes, and will be structured as follows: - one questions on the experimental characterization of materials; - one question on IR Thermography techniques; - one question on Digital Image Correlation techniques and other optical techniques; - one question on the finite element method; - a question on the application of the finite element method to biomechanics; - overview of the course report together with the examiner, who can ask some specific comments or explanations on the content of the report.

	All questions will require an oral discussion. Furthermore, some questions may require some short math demonstrations, writing of important equations, or sketch drawings. The following aspects of the exam performance will be considered and marked by the lecturer: a) The level of details and ability to make comparisons and links among techniques and with experiences learned during the lab activities; b) The clearness of the answer and proper use of technical terminology; c) The effectiveness of using graphical and mathematical representations to derive knowledge and supplement the oral exposition; d) The quality of the lab report in terms of: completeness of content, rigor of data post-processing and interpretation of results, general originality/effectiveness in the graphical presentation of the report. The above described four performance factors (a,b,c,d) will receive a separate mark that can be: excellent (9 points): Very good knowledge of all topics and relative interactions (a), very good technical language skills (b), Very good ability to derive analytically answers to problems (b,c,d), the student is able to apply the knowledge in an elegant and effective way to solve problems and answer questions (c,d), The student is able to organize, describe and communicate the results and test setups in a very elegant, synthetic and effective way, providing an overall original contribution (d). Good (7 points): Good knowledge of all topics (a), good technical language skills (b), good ability to apply the knowledge to derive answers to problems (b,c,d), The student is able to organize, describe and communicate the results and test setups in an effective way (d). Sufficient (6 points): has a complete knowledge of topics but shows a limited ability to use such knowledge (a), comprehensible technical language skills (b), the student has a limited ability to describe and solve problems analytically, with only sufficient drawing skills (c,d), The student is able to organize, describe and communicate the results and test setups in a sufficient way (d). Mediocre (4 points): has a not-complete knowledge of topics and shows an almost null ability to use such knowledge (a), low technical language skills (b), the student has a null ability to describe and solve problems analytically without the help of the teacher (c,d), The student organizes, describes and communicates the results and test setups in a confused and often misleading way, with low level of details (d). Insufficient (0 points): his knowledge of topics is unacceptably limited (a,b,c), the lab report is copied from the work of colleagues and the student does not demonstrate to have understood its content, is not able to justify choices made, and does not demonstrate to have contributed to its preparation (d), the lab reports contain macroscopic errors on the description of setups and data treatment (d). The final mark will result from adding the scores assigned to each performance factor: a,b,c,d. An example is as follow: a=7, b=6, c=4, d=0 will gain a final mark of 17. The maximum vote of 30&Lode is obtained when the total score is higher than 30.
TEACHING METHODS	The whole course comprises two modules: one equivalent 6 CFU and one to 3 CFU. The first module of 6 CFU will focus on topics of Experimental Biomechanics, and will amount to 36 hours of lectures and 18 hours of laboratory activities. Lectures will consist of oral presentations assisted by the contemporary use of multimedia power-point projection and checkboard. Lab activities, whenever possible, will be held in lecture theatre O007, which is equipped as a didactic laboratory for the implementation of experimental mechanical characterisation setups. Some lab activities will be held in the "Laboratorio Prova Materiali e Componenti" (O002). Here students will be introduced to some common testing facilities for materials mechanical testing, such as electro-mechanic and servo-hydraulic universal testing machines and typical accessories and transducers for the characterization of the mechanical behaviour of materials and structures. The 3 CFU module will cover the topics of Computational Biomechanics and will consist of 16 hours of lectures and 11 hours of group activity using computer programs based on the finite element method, for a total of 27 hours (9 hours for credit for a total of 3 credits). The lectures will mainly consist of oral

	presentations by the lecturer given with the help of power-point slides and sometime blackboard. The activities of use of computer programs require students to gain the ability to address and solve problems of Biomechanical interest through commercial codes for numerical simulations in their free version for students (educational).

MODULE
PROSTHESIS AND ORTHOSES COMPUTATIONAL BIOMECHANICS

Prof. GIUSEPPE PITARRESI

SUGGESTED BIBLIOGRAPHY

F. Cappello, A. Pantano - Appunti e slides del corso. The lecturer's slides and notes will be available from a web repository.
G.Belingardi: "Principi e metodologie della progettazione meccanica", Levrotto & Bella, 1995
O.C. Zienkiewicz, R.L. Taylor: "The finite element method" - McGraw Hill Book Company, London, 1989
J. N. Reddy: "An Introduction to the Finite Element Method", McGraw Hill Book Company, London, 1993.
S.L. Crouch, A.M. Starfield: "Boundary element meth. in solid mechan.", G. Allen & Unwin, London, 1983
V. Hubka, W.E. Eder: "Design science" – Springer, London, 1992.

AMBIT	20909-Attivit Formative Affini o Integrative
INDIVIDUAL STUDY (Hrs)	48
COURSE ACTIVITY (Hrs)	27

EDUCATIONAL OBJECTIVES OF THE MODULE

The course provides knowledge on the main computational techniques for measuring stresses, deformations and displacements in biomaterials, materials for prostheses and endoprostheses, and related components or structures. The computational evaluation of these quantities is fundamental for the mechanical characterization of materials, and therefore for their choice and use in the design of prostheses. The student will learn the theory of finite elements and its use to numerically simulate typical problems of the design of prostheses and orthoses through commercial programs. The student will be able to analyze the results of the simulations conducted and to refine the numerical models in order to obtain accurate results. The student who chooses the course will be able to achieve a wide, complete and highly professionalizing training in the areas of development of innovative structural materials, their use in structural design in the bio-engineering field. In addition, the computational simulation activities will provide adequate training for carrying out research of high technical-scientific profile, both in the industrial and academic fields.

SYLLABUS

Hrs	Frontal teaching
16	Introduction to the course. Displacement method. Finite element method (FEM). Shape functions. Stiffness matrix of the element and of the structure. Boundary conditions. Evaluating displacements and strains. Convergence criteria. Displacement functions with generalized coordinates. Type of elements: one dimensional, plane, plate, shell, solid tetrahedra, parallelepipeds. Isoparametric element. Numerical integration. Discretization criteria. Hierarchical elements. Nonlinear analysis. Dynamic problems. Implicit and explicit integration methods. Use of commercial codes based on FEM for the analysis of mechanical components and structures. Examples of mechanical problems solved with framed elements (rods or beams), plane elements, axisymmetric elements, solid elements, shells elements. Analysis of composite structures. Problems with geometric nonlinearity. Buckling. Nonlinearities of the material. Contact problems. Analysis of thermal and thermomechanical problems. Modal analysis. Analysis of harmonic response. Dynamic Analysis. Modeling of the mechanical behavior of biological tissues, constitutive formulation and non-homogeneous distribution of mechanical properties. Analysis of biomechanical components, in particular prostheses and orthoses. Modeling of bone tissue.

Hrs	Practice
11	Use of commercial codes based on FEM for the analysis of mechanical components and structures. Examples of mechanical problems solved with framed elements (rods or beams), plane elements, axisymmetric elements, solid elements, shells elements. Analysis of composite structures. Problems with geometric nonlinearity. Buckling. Nonlinearities of the material. Contact problems. Analysis of thermal and thermomechanical problems. Modal analysis. Analysis of harmonic response. Dynamic Analysis. Analysis of biomechanical components and bone tissues.

MODULE PROSTHESIS AND ORTHOSES EXPERIMENTAL BIOMECHANICS *Prof. GIUSEPPE PITARRESI*	
SUGGESTED BIBLIOGRAPHY	
[1] A. Ajovalasit, D. Cerniglia, G. Petrucci, G. Pitarresi – Introduzione ai metodi di Meccanica Sperimentale dei Solidi. Ed. Aracne, Marzo 2018 (ISBN: 978-88-255-1152-9). [2] G. Pitarresi – Appunti e slides del corso (slides and notes). The lecturer's slides and notes [2] will be available from a web cloud repository.	
AMBIT	20909-Attivit Formative Affini o Integrative
INDIVIDUAL STUDY (Hrs)	96
COURSE ACTIVITY (Hrs)	54
EDUCATIONAL OBJECTIVES OF THE MODULE	
The aim of this course is to introduce students to some of the more advanced experimental techniques used for the measurement of displacements, strains and stresses in materials and structures. A specific reference will be made to the evaluation of biomaterials in general and materials best suited for the realization of prostheses and orthopedic aids. The experimental evaluation of stress/strain/displacements is in in particular aimed at the material mechanical characterization with reference to its constitutive models and stiffness/strength response, at the validation of analytical and numerical design models of the structural response of prostheses, and at the evaluation of the mechanical functional requirements of prostheses. Students will learn about the theoretical and practical fundamentals for the implementation of some of the most influential experimental stress analysis techniques used in modern Experimental Mechanics.	

SYLLABUS

Hrs	Frontal teaching
8	Basics on strength of structural materials: brittle and ductile behavior, static and fatigue strength. A general overview of standard tests for the mechanical characterization of materials. Description of the principal universal testing machines and accessories for the measurement of mechanical parameters. Tensile behavior characterization of isotropic and anisotropic materials. Shear and flexural tests on metallic, polymer, and polymer composite materials.
7	Transduces based on electrical strain gauges for the measurement of forces, displacements, deformations. Electrical Strain Gauges (ER): Features of ERs (2), selection criteria for ERs (1), the Wheatstone bridge circuit for electrical resistance measurements (1), ER installation configurations for simple loading cases (1), influence of leads in Wheatstone bridges for ERs (1.5), Shunt calibration of Wheatstone bridge (0.5),
16	Structural characterization of bio-materials and prostheses by means of optical techniques. Digital Image Correlation methods: Digital Image Correlation 2D (6): Deformation of subsets and shape functions ;Correlation functions and their optimization; evaluation of strains from the displacement field; Experimental implementation of DIC techniques;Systematic and random errors in DIC; Digital Image Correlation 3D (2). Digital Volume Correlation (1) Particle Image Velocimetry (PIV) (1). Biomedical applications of DIC methods (3) Fibre ottiche con reticolo di Bragg per la misura di temperature e deformazioni (3).
8	Thermal Methods for Structural Analysis. Infrared Thermography: basic concepts on radiation heat transfer (1); Problems related with measurement of temperature from Infrared Thermal Cameras (1); Analysis of the thermographich signal in the frequency domain (2); Biomedical applications of IR Thermography (1). Thermo-mechanical behaviour of NiTi and Shape Memory Alloy (3).

Hrs	Workshops
3	Mechanical characterisation of bio-materials. Experimental implementation of tensile and flexural tests on metallic, polymeric and composite materials.
6	Measurement setups by means of Electrical strain gauges. bonding and check-up of a single grid ER gage (2). measurements with various ER configurations (1). measurements with ER rosettes on polymer matrix composite materials (1). conditioning and measurements with strain gauge transducers (load cells, extensometers, etc...), and use of data loggers (2).

6	Implementation of a thermographic active IR structural monitoring NDT technique with an Infrared camera (2). Implementation of a DIC-2D setup by means of the N-Corr software (2). Combined use of DIC and IR Thermography techniques for the thermo-mechanical characterisation of NiTi alloys (2).