UNIVERSITÀ DEGLI STUDI DI PALERMO

DEPARTMENT	Ingegneria
ACADEMIC YEAR	2019/2020
MASTER'S DEGREE (MSC)	BIOMEDICAL ENGINEERING
SUBJECT	COMPUTATIONAL AND EXPERIMENTAL PROSTHESIS AND ORTHOSES BIOMECHANICS
TYPE OF EDUCATIONAL ACTIVITY	C
AMBIT	20909-Attivit Formative Affini o Integrative
CODE	20274
SCIENTIFIC SECTOR(S)	ING-IND/14
HEAD PROFESSOR(S)	PITARRESI GIUSEPPE Professore Ordinario Univ. di PALERMO
OTHER PROFESSOR(S)	
CREDITS	9
INDIVIDUAL STUDY (Hrs)	144
COURSE ACTIVITY (Hrs)	81
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	A basic knowledge of the below listed subjects is advised to help a full and prompt understanding of Experimental Stress Analysis topics: - Maths: Tensorial Calculus, Complex Numbers, Trigonometry, - Phisics: basic notions of Electrical Circuits, notions of Heat Transfer by conductivity and irradiance, notions of Electromagnetism. - 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, Isotropic/Orthotropic behaviour, Generalised Hook's law and Thermal stresses. - Mechanics of Materials: Ductile and brittle behaviour, Elastic stiffness/compliance parameters, basic Fracture Mechanics, Static and Fatigue strength behaviours.
LEARNING OUTCOMES	Knowledge and comprehension of: Students attending the course will gain knowledge on five main approaches of Experimental Mechanics: 1) Use of universal testing machines for the mechanical characterisation 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. Students will in particular learn how the temperature of structures can be processed in the time or frequency domain for retrieving information on the stress field (Thermoelastic Stress Analysis) or the structural integrity (InfraRed Non-Destructive Testing) of materials and components. 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. It is finally observed that the knowledge gained on Electrical Strain Gauges and IR Thermography is useful to gain the second level qualification as personnel performing industrial Non-Destructive Testing, according to the International standard EN ISO 9712. 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 characterisation; - 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; - condition and measure with electrical strain gauge based transducers such as load cells or extensometers; - operate IR Cameras and interpret correctly thermograms from different environment conditions; - post-process thermal data in the time and frequency domains, and propose setups of Passive and Active Thermography; - 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. - analyse, solve and optimize problems typical of 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. More in general students will be able to: - Select the most appropriate experimental stress analysis technique based on the material/component to analyse and information to retrieve; - Choose and setup the instrumentation for the specific technique; - perform the measurements; - record and classify data and results from testing; - present data through reports.

	- use commercial codes based on the finite element method - simulate the mechanical behaviour of biomechanical prosthesis and orthosis
ASSESSMENT METHODS	The exam will be split into two consecutive sessions: one related to the Experimental Biomechanics module, and one related to the Computational Biomechanics module. A constant attendance of the course is considered an important prerequisite to access examination. In particular attendance of the 70 % of lab hours and of the activities of use of computer programs is considered essential. In fact the experience gained in the lab is unique and hardly achievable by any self-preparation. Furthermore, the report on the lab activities and one on the activities of use of computer programs, to be prepared by each student singularly, will be subject to evaluation and contribute to the final mark. Students who book for their examination must submit their reports on lab activities and on the activities of use of computer programs to the lecturer with at least one week advance from the day of the exam. The report can also be provided in electronic version by email. A typical exam will last between 30 and 60 minutes, and will be structured as follows: - one questions on the experimental characterisation of materials; - one question on IR Thermography techniques; - one question on Digital Image Correlation techniques and other optical techniques; - overview of the lab report together with the examiner, who can ask some specific comments or explanations on the content of the report. A typical exam will last between 30 and 60 minutes, and will be structured as follows: - two questions on the finite element method; - a question on the application of the finite element method to biomechanics; - revision of the report on the use of computer programs. The teacher at this stage will be able to request 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, among solutions 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.
EDUCATIONAL OBJECTIVES	The course provides knowledge on techniques for the experimental and computational measurement of stresses, strains and displacements on bio-materials, materials used for the fabrication of prostheses, and their relative structures. Such quantities are fundamental for the evaluation of structural performances and mechanical characterisation, and are also of uttermost importance for the validation of numerical and analytical models. Students will learn the theoretical background and implementation schemes of some of the most influential and updated techniques used in Experimental Mechanics, which can be applied for the evaluation of complex structures as well as the characterization of the mechanical behaviour of traditional and innovative bio-materials. Students will learn the theory of finite elements and its use to numerically simulate typical problems of prosthesis and orthosis design through commercial programs. The student will be able to analyse the results of the simulations carried out and to refine the numerical models in order to obtain accurate results. Moreover, the planned laboratory and computational simulation activities will provide skills useful for any prospective of engagement in scientific research activities, in both industrial or academic contexts.
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 the topics of Experimental Biomechanics, and will amount to 36 hours of lectures and 18 hours of laboratory group activities for a total of 54 hours (9 hours per credit for a total of 6 credits). Lectures will consist of oral presentations assisted by the contemporary use of multimedia power-point projection and checkboard. Checkboard will be preferred for topics with prevalent analytical and mathematical developments, while power-point for more effective graphical representations and video tutorials. Lab activities will be held in lecture theatre O007, which is equipped as a didactic laboratory for the implementation of experimental setups regarding Electrical Strain Gauges (installation and measurement), IR Thermography, Digital Image Correlation and Photoelastic Stress Analysis. Some lab activities will be held in the "Laboratorio Prova Materiali e Componenti" of the DICGIM department (O002). Here students will find and 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).
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. [3] F. Cappello, A. Pantano - Appunti e slides del corso. The lecturer's slides and notes will be available from a web repository.

SYLLABUS

Hrs	Frontal teaching
7	Basics on strength of structural materials: brittle and ductile behavior, static and fatigue strength. 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 behaviour characterisation of isotropic and anisotropic materials. Shear andflexural tests on metallic, polymer and polymer composite materials
7	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), processing of in-plane strain data from single and rosettes ERs (1.5), strain data processing on orthotropic materials (0.5). (in brackets the hours spent for each topic).
10	Thermal Methods for Structural Analysis. Infrared Thermography: basic concepts on radiation heat transfer (1.5); Problems related with measurement of temperature from Infrared Thermal Cameras (1.5); State of the art on commercial IR Camera Systems (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)
12	Optical Methods: digital image correlation techniques. Principle of two-dimensional DIC (1 hour); Displacements and deformations in the Continuum Mechanics: Deformation of subsets and shape functions (0.5 hour); Determination of strains (0.5 hour); Correlation functions and their optimization (1.5 hour); The evaluation of strains from the displacement field (0.5 hour); Experimental implementation of DIC techniques: Preparation of samples and characteristics of speckles (0.5 hour); Optical setup and image acquisition (1 hour); Systematic and random errors in DIC (1 hour); Stereo Digital Image Correlation: the three dimensional case (1 hour); Calibration of the stereo-vision system (0.5 hour); Determination of shape and displacements (0.5 hour); Basics principles of Digital Volume Corrrelation (0.5 hour). Determinazione della forma e degli spostamenti (0.5). Particle Image Velocimetry (PIV) and related bio-medical applications (3)
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.

Hrs	Workshops
18	Characterisation of materials - Implementation of tensile tests on metallic, polymer and polymer composite materials (execution of tensile tests on servo-hydraulic and electro-mechanic testing machines) (3 hours). ER Strain Gauges_1 - installation and checkup of a single grid ER gage on a steel component (3 hours). ER Strain Gauges_2 - measurements on bending beams and ERs with various configurations (2 hours). ER Strain Gauges_3 - measurements with ER rosettes from metallic and polymer matrix composite materials (2 hours). ERStrainGauges_4 - conditioning and measurements with strain gauge transducers (load cells, extensometers, etc...), and use of data loggers (2 hours). IR Thermography_1 - determination of the Emissivity of a generic real material according to an ASTM standardized procedure (1 hour). IR Thermography_2 - implementation of an active IR NDT technique for NDT evaluation (2 hour). DIC_1: Implementation of a DIC-2D setup by means of the N-Corr software (2 hours). DIC_2 + IR Thermography 4: combined use of techniques for the thermos-mechanical characterisation of NiTi alloys (2 hours).