ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

43000600 - FabricaciÓn Avanzada De Materiales Estructurales

DEGREE PROGRAMME

04AN - Master Universitario En Ingenieria De Materiales

ACADEMIC YEAR & SEMESTER

2023/24 - Semester 1

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	43000600 - Fabricación Avanzada de Materiales Estructurales
No of credits	3 ECTS
Type	Compulsory
Academic year ot the programme	First year
Semester of tuition	Semester 1
Tuition period	September-January
Tuition languages	English
Degree programme	04AN - Master Universitario en Ingenieria de Materiales
Centre	04 - Escuela Tecnica Superior De Ingenieros De Caminos, Canales Y Puertos
Academic year	2023-24

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Andres Diaz Lantada (Subject coordinator)	Por email	andres.diaz@upm.es	Sin horario.
Francisco Franco Martinez	Por email	francisco.franco@upm.es	Sin horario.
Juan Manuel Muñoz Guijosa	Por email	juanmanuel.munoz.guijosa@upm.es	Sin horario.

Jon Mikel Molina Aldareguia	Por email	jon.molina@upm.es	Sin horario.

* The tutoring schedule is indicative and subject to possible changes. Please check tutoring times with the faculty member in charge.

3. Skills and learning outcomes *

3.1. Skills to be learned

CB07 - Que los estudiantes sepan aplicar los conocimientos adquiridos y su capacidad de resolución de problemas en entornos nuevos o poco conocidos dentro de contextos más amplios (o multidisciplinares) relacionados con su área de estudio

CE3 - Capacidad de diseñar, modelizar, evaluar, seleccionar, fabricar y utilizar materiales con propiedades específicas (estructurales y funcionales) para satisfa

CE4 - Autonomía para adquirir, analizar, actualizar y aplicar nuevos conocimientos, modelos y técnicas experimentales y numéricas en relación con la composición y estructura de los materiales, su caracterización física y química, sus procesos de fabricación, su utilización y aplicación científica y tecnológica, y su reciclado, reutilización y eliminación / Autonomy to acquire, analyze, update and apply new knowledge, models and experimental and numerical techniques related to the composition and structure of materials, their physical and chemical characterization, their manufacturing processes, their use and scientific and technological application, and their recycling, reuse and disposal

CE9 - Capacidad de realizar un trabajo o proyecto individual integrando y relacionando las competencias adquiridas en las distintas asignaturas del máster, junto con la capacidad de defenderlo en público ante un tribunal universitario experto en el tema del trabajo / Ability to carry out an individual job or project integrating and relating the skills acquired in the different subjects of the master's degree, together with the ability to defend it in public before an expert university panel on the topic of the job

CG3 - Trabajo en equipo: Los alumnos desarrollan la capacidad para trabajar en equipo, integrarse y colaborar de forma activa en la consecución de objetivos comunes / Teamwork: Students develop the ability to work as a team, integrate and actively collaborate in achieving common goals.

CG4 - Creatividad: Los alumnos son capaces de resolver de forma nueva, original y aportando valor, situaciones o problemas en el ámbito de la ingeniería de materiales / Creativity: Students are able to solve situations or problems in the field of materials engineering in a new, original way and adding value.

CG5 - Organización y planificación: Los estudiantes son capaces de fijar objetivos, con la planificación y programación de actividades (tiempo y fases) y con la organización y gestión de los recursos necesarios para alcanzarlos / Organization and Planning: Students are capable of setting objectives, with the planning and programming of activities (time and phases) and with the organization and management of the necessary resources to achieve them..

CG7 - Uso de las TIC: Los alumnos son capaces de aplicar conocimientos tecnológicos necesarios de manera que les permitan desenvolverse cómodamente y afrontar los retos que la sociedad les va a imponer en su quehacer profesional empleando la informática / Use of ICT: Students are able to apply the necessary technological knowledge in a way that allows them to function comfortably and face the challenges that society is going to impose on them in their professional work using computers.

CG8 - Resolución de problemas: Los estudiantes son capaces de reconocer, describir, organizar y analizar los elementos constitutivos de un problema para idear estrategias que permitan obtener, de forma razonada, una solución contrastada y acorde a ciertos criterios preestablecidos / Problem solving: Students are able to recognize, describe, organize and analyze the constitutive elements of a problem to devise strategies that allow obtaining, in a reasoned way, a contrasting solution and according to certain pre-established criteria.

3.2. Learning outcomes

RA26 - Saber utilizar y aplicar las técnicas y modelos matemáticos de simulación para predecir el comportamiento y evolución de los materiales. Saber evaluar su seguridad, durabilidad e integridad estructural y la de los componentes fabricados con ellos

RA28 - Design simple structural elements with different materials

RA30 - C2 - Knowledge of the physical-chemical, structural, optical, electrical and magnetic properties of advanced structural and functional materials

RA31 - C3 - Knowledge of the main advanced models of materials design through simulation: finite elements, atomistic modeling, homogenization theory, topological optimization, Classical Laminate Theory, IA and machine learning

RA4 - Que los estudiantes sepan comunicar sus conclusiones (y los conocimientos y razones últimas que las sustentan) a públicos especializados y no especializados de un modo claro y sin ambigüedades

RA22 - Ser creativo, ejecutando el trabajo con responsabilidad y respeto a los demás

* The Learning Guides should reflect the Skills and Learning Outcomes in the same way as indicated in the Degree Verification Memory. For this reason, they have not been translated into English and appear in Spanish.

4. Brief description of the subject and syllabus

4.1. Brief description of the subject

Motivation:

Since the dawn of civilization, the forerunners of civil, materials and mechanical engineering searched for structural materials capable of supporting humankind, in the pursue of enhanced life quality, thanks to infrastructures, constructions, and machines with progressively growing structural demands. The industrial revolutions of Modern and Contemporary eras were fundamental for the development of materials science and engineering, which enabled and led to additional generalized expectations from structural materials, beyond the traditional strength and stiffness requirements, towards improved processing, greater productivity, enhanced aesthetics and usability, increased strength vs weight ratios, among others.

More recent advances in computer-aided design methods and computational modeling resources have enabled the discovery and optimization of new knowledge-based, multiscale, and multifunctional synthetic structural materials. Being designed with the support of computational tools, these innovative materials are sometimes called ?digital materials?. Synergic advances in micro and nanomanufacturing tools and in additive manufacturing technologies have made possible the complex-shaped creation and processing of such advanced structural materials, in which the designed structures or architectures play an essential role in the final properties, even greater than the chemistry of the raw material used to achieve such material structures. Additional combinations of these processing advances with progresses in the field of active materials, capable of responding or interacting with the environment in a controlled way, have led to highly innovative features of advanced structural materials, which are now designed for minimized eco-impacts, using lightweight design strategies, incorporating functional gradients of properties, and searching for ?smart? functionalities. These advanced design and processing tools for structural materials are opening new horizons in a wide set of fields and industries: space, energy, transport, automation, and robotics, electronic, biomedical and architecture, to mention a few.

UPM has a remarkable research background in the field of advanced structural materials and related processes, with expertise in materials computational modeling, in modern manufacturing technologies and in the application of synthetic materials for relevant societal problems. This experience will be now disseminated through a new course on ?Advanced design and manufacturing of structural materials?, for training a new generation of materials engineers capable of unfolding the potentials of highly special processing strategies, applied to innovative structural materials, for the benefit of society.

Learning objectives:

At the end of the course, students should have acquired the following set of high-level learning objectives, which drive the global pedagogical strategy:

O.1. Understanding the concept, fundamental principles, design methods, processing technologies, current industrial relevance, and future potentials of advanced structural materials, as an emergent field in materials science and engineering.

O.2. Ability to design engineering products, in which specially architectured materials play an essential role, towards innovative functionalities, improved performance, enhanced reliability, optimised efficiency or reduced eco-impacts.

O.3. Comprehension of the existing manufacturing options for creating polymeric, metallic, ceramic, composite, and biological advanced structural materials, for integrating them into engineering systems, infrastructures, and buildings, planning the related production processes.

O.4. Capability to promote research and innovation strategies in the field of advanced structural materials and to create derived value proposals towards viable entrepreneurial activities linked to a wide set of industries.

Teaching methodology:

According to the ECTS definition, a 3-ECTS course corresponds to a total of 75-90 hours of student dedication for adequate fulfilment of the learning objectives and proposed outcomes development. Considering the 15 above-listed sessions of 2 hours and a study factor of 0.5 hours per hour of class, each student will devote around 45 hours to the sessions and related direct application tasks (see personal portfolio in ?assessment? below). The remaining 30-45 hours, required to complete the expected dedication, will be devoted to application projects following the CDIO approach and working in teams, as described below (see subsection b).

a) Lectures, seminars, visits and hands-on activities

In situ sessions include lectures, seminars, visits, and hands-on activities, all of them planned as two-hour sessions with combinations of theoretical and practical tasks. Lectures will provide the fundamentals and seminars will present avant-garde research and innovation directions and results.

The visits to UPM's Product Development Laboratory, to IMDEA Materials and to UPM?s research and technological centres will help to involve students in real working environments, in which R&D tasks in the field of advanced structural materials are performed daily.

Hands-on activities will be performed in a dedicated collaborative design computer room with all necessary software resources for designing and simulating microarchitectured materials and for integrating them into advanced engineering systems. These practical sessions will introduce students to the design and simulation fundamentals, as regards advanced structural materials and their application to engineering systems. Apart from developing a collection of case studies, as part of their personal portfolios, in these sessions, students will learn how to use modern engineering tools, which will be also applied in parallel to their application CDIO projects.

All lectures and seminars will be recorded and made available, as open-source teaching-learning materials, which will support remote study and may help with eventual e-learning, b-learning and m-learning adaptations of the course. The introductions to the hands-on activities will be also recorded and shared as tutorials or webinars, for helping students complete their hands-on tasks (for their personal portfolios) at home, using open source and available software resources, without necessarily having to visit the collaborative design computer room.

b) CDIO projects

Learning by doing is arguably the most adequate approach to education at all levels, but especially applies to modern engineering education, due to the fundamental impact of students motivation in the learning results and to the fact that engineering professional practice relies on combining theory and practice for solving societal problems, while advancing science and technology. In consequence, the course will follow the CDIO (conceive-design-implement-operate) approach, a holistic project-based learning (PBL) model, in which students live through the complete innovation cycle, reaching up to the prototyping and testing stages, of all kinds of engineering products, processes and systems. The CDIO model perfectly adapts to the learning objectives and to the expected outcomes of the proposed ?Advanced design and manufacturing of structural materials' course.

At the beginning of the course, students will be grouped in teams of 3 or 4 companions, which will live through a complete CDIO cycle in one semester, applying lessons learned along the course to a real engineering project.

Each team of students will focus on the conceptualization, design, manufacturing and testing of an engineering product or system, in which the use of advanced structural materials provides an objective advantage, in terms of functionality, performance, reliability, efficiency or reduced eco-impacts: starting from an unsolved or partially solved societal need, related to industrial areas related to the course's topics (space, energy, transport, automation and robotics, electronic, biomedical devices and architecture), students will de novo design the structure of an engineering product or optimize the structures of a set of components from an existing device, in all cases focusing on the application of advanced structural materials and on the related design and manufacturing technologies.

Requisites for the CDIO projects include: 1) conceptualizing a solution to a real engineering problem, in which an advanced structural material plays a fundamental role; 2) designing and modelling the advanced structural material; 3) integrating the advanced structural material as relevant part of the final product?s or system?s structure; and 4) manufacturing and validating the proposal with a conceptual prototype (?printing my design: from CAD models to prototypes?), which will also help to propose continuation directions. A final public presentation with debate among groups will be an essential part of the evaluation and contribute to peer-to-peer learning.

A total of between 90 and 180 hours, depending on the number of students per team and on the dedication range per ECTS, will be devoted to each CDIO project on microarchitectured materials. As compared with more traditional PBL approaches, CDIO stands out for a more global view (and more enjoyable learning process), which puts forward the relevance of reaching the prototyping and experimental stages, as necessary phases for learning while designing engineering systems.

Resources for the CDIO application projects include the design, simulation, and manufacturing technologies available at UPM's Product Development Laboratory. Computer-aided design, engineering and manufacturing resources, such as Siemens NX, Catia, Comsol, n-Topology, will synergize with medical imaging processing tools (i.e. 3D Slicer), for promoting personalized design approaches, and with high-level programming resources (i.e. Matlab and Simulink, Python), for developing ad hoc calculations and consequent design or production optimizations.

In terms of manufacturing tools, the well-equipped digital manufacturing lab will support students with technologies like multi-material fused deposition modelling, laser stereolithography, vacuum casting, mould making facilities, compression moulding, UV photolithography, bioprinting and state-of-the-art CNC machining equipment, for implementing and validating their designs. A wide set of characterization and testing systems are also available.

Possible topics for the CDIO projects, although ideally students' teams will propose their topics of interest for the teamwork PBL activity, include:

- Design and manufacturing of structural elements with innovative materials and geometries.

- Design and manufacturing of actuators using smart structures for robotics and space.

- Design and manufacturing of functionally graded tissue scaffolds for osteochondral repair.

- Design and manufacturing of personalized prostheses with biomechanical performance.

- Topology optimization of mechanical components aimed at lightweight performance.

- Topology optimization of mechanical components aimed at minimal eco-impacts.

- Integration of structural and thermal functions in high performance machine elements.

- Improved production by integration of components redesigned for additive manufacturing.

- Investigation of natural hierarchical materials for biomimetic structural design.

- Investigation of biointerfaces as inspiring surfaces for advanced materials and structures.

- Design of self-sensing structural materials and self-sensing components and structures.

- Design of advanced structural materials and structures using 4D printing principles.

c) Featured manufacturing technologies

Along the course, several manufacturing technologies, which enable the creation of advanced structural materials, and related applications, using polymers, ceramics, alloys, composites, and biological raw materials, will be presented an analysed. Traditional industrial techniques, such as CNC machining, casting, sintering, forging, rolling, injection, and compression moulding, will be presented in parallel to different application cases. Special attention will be paid to solid freeform fabrication methods, due to their fundamental impact on the emergent field of advanced structural materials. From solid freeform fabrication or additive manufacturing technologies, the course will present, and illustrate with case studies, alternatives including fused deposition modelling, laser stereolithography, digital light projection, two-photon polymerization, lithography-based ceramic manufacture, multi-jet fusion, selective laser sintering, powder-based laser fusion and bioprinting. Surface micromanufacturing resources will be also illustrated, focusing on techniques like UV photolithography, electron beam lithography, deep reactive ion etching, X-ray lithography and LIGA, for achieving improved surface functionalities. Chemical and physical vapour deposition processes, laser material processing, dip-pen nanolithography, polymer pen lithography and other surface functionalization techniques will be also featured.

d) Available case studies

The application-oriented strategy of the course will be supported by a collection of case studies, consequence of research experiences and international collaborations, in which the team of professors has been recently involved. These case studies will provide students examples for their CDIO projects and cover most industrial areas, for which advanced structural materials play an essential role: space, energy, transport, automation and robotics, electronic, biomedical devices, and architecture, to cite a few. A collection of related designs and prototypes is available: topology- and topography-optimized materials and structures for transport, space and robotics (i.e. freeform design of motorbike break lever, optimized vehicle chassis, unconventional bike rim); prostheses manufactured with advanced materials and structures; polymers, ceramics and alloys as personalized tissue engineering scaffolds for bone and cartilage repair; smart and self-sensing materials integrated into industrial applications; cellular structures for autonomous deployable structures; heat exchangers and cooling devices with integrated thermal, fluidical and structural functions, among others.

4.2. Syllabus

1. Introduction to advanced structural materials
2. Overview of additive manufacturing technologies for structural materials
3. Computer-aided design of advanced structural materials
4. Finite element modeling of advanced structural materials
5. Shape-morphing structures and 4D printing
6. Topology and topography optimization of advanced structural materials
7. Hierarchical and fractal geometries: design and manufacturing
8. Artificial intelligence aided design and manufacturing of structural materials
9. Advanced manufacturing of structural polymers
10. Advanced manufacturing of structural alloys
11. Advanced manufacturing of structural ceramics
12. Advanced manufacturing of structural composites
13. Advanced manufacturing of structural carbon based materials
14. Advanced manufacturing of structural smart & living materials
15. Visit to UPM's Product Development Laboratory
16. Visit to materials research institute / facility
17. Presentation of CDIO projects

5. Schedule

5.1. Subject schedule*

Week	Classroom activities	Laboratory activities	Distant / On-line	Assessment activities
1	**Tema 1** Duration: 02:00 Lecture			
2	**Tema 2** Duration: 02:00 Lecture			
3	**Tema 3** Duration: 02:00 Problem-solving class			**Delivery of individual design excercise** Individual work Continuous assessment and final examination Presential Duration: 02:00
4	**Tema 4** Duration: 02:00 Problem-solving class			**Delivery of individual simulation excercise** Individual work Continuous assessment and final examination Presential Duration: 02:00
5	**Tema 5** Duration: 02:00 Lecture			
6	**Tema 6** Duration: 02:00 Lecture			
7	**Tema 7** Duration: 02:00 Problem-solving class			**Delivery of design exercise** Individual work Continuous assessment and final examination Presential Duration: 02:00
8	**Tema 8** Duration: 02:00 Problem-solving class			**Delivery of design exercise** Individual work Continuous assessment and final examination Presential Duration: 02:00
9	**Tema 9** Duration: 02:00 Lecture			
10	**Tema 10** Duration: 02:00 Lecture			

11	**Tema 11** Duration: 02:00 Lecture			
12	**Tema 12** Duration: 02:00 Lecture			
13	**Tema 13** Duration: 02:00 Lecture			
14	**Tema 14** Duration: 02:00 Lecture			
15	**Tema 15 (visita)** Duration: 02:00 Additional activities			
16	**Tema 16 (visita)** Duration: 02:00 Additional activities			
17	**Presentation of CDIO projects** Duration: 02:00 Additional activities			**Presentation of CDIO projects** Group work Continuous assessment and final examination Presential Duration: 02:00

Depending on the programme study plan, total values will be calculated according to the ECTS credit unit as 26/27 hours of student face-to-face contact and independent study time.

* The schedule is based on an a priori planning of the subject; it might be modified during the academic year, especially considering the COVID19 evolution.

6. Activities and assessment criteria

6.1. Assessment activities

6.1.1. Assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
3	Delivery of individual design excercise	Individual work	Face-to-face	02:00	5%	5 / 10	CB07 CE3 CE9 CG8
4	Delivery of individual simulation excercise	Individual work	Face-to-face	02:00	5%	5 / 10	CE3 CE9 CG8 CB07
7	Delivery of design exercise	Individual work	Face-to-face	02:00	5%	5 / 10	CB07 CE3 CE9 CG8
8	Delivery of design exercise	Individual work	Face-to-face	02:00	5%	5 / 10	CB07 CE3 CE9 CG8
17	Presentation of CDIO projects	Group work	Face-to-face	02:00	80%	5 / 10	CB07 CE3 CE4 CE9 CG3 CG4 CG8 CG7 CG5

6.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
3	Delivery of individual design excercise	Individual work	Face-to-face	02:00	5%	5 / 10	CB07 CE3 CE9 CG8

4	Delivery of individual simulation excercise	Individual work	Face-to-face	02:00	5%	5 / 10	CE3 CE9 CG8 CB07
7	Delivery of design exercise	Individual work	Face-to-face	02:00	5%	5 / 10	CB07 CE3 CE9 CG8
8	Delivery of design exercise	Individual work	Face-to-face	02:00	5%	5 / 10	CB07 CE3 CE9 CG8
17	Presentation of CDIO projects	Group work	Face-to-face	02:00	80%	5 / 10	CB07 CE3 CE4 CE9 CG3 CG4 CG8 CG7 CG5

6.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Presentation of an individual project linked to the design, optimization, prototyping and testing of an structural component.	Individual work	Face-to-face	02:00	100%	5 / 10	CB07 CE3 CE4 CE9 CG3 CG4 CG8 CG7 CG5

6.2. Assessment criteria

The course is conceived in a project-oriented way. Teams of students will cocreate innovative structural elements and live through their whole specification, design, optimization, prototyping and testing. The projects will account for a 80% of the final mark. Individual applied tasks directly derived from practical activities in the design room will account for a 20% of final mark and help to individualize the evaluation.

If a student opts for directly attending the final examination, an individual project linked to the design, optimization, prototyping and testing of an structural element will account for the 100% of the final mark. This situation is not ideal, as a fundamental aspect of CDIO projects and project-based learning is teamwork and related cocreation experiences.

7. Teaching resources

7.1. Teaching resources for the subject

Name	Type	Notes
Publications from the team of professors	Bibliography	Different publications describing the advanced manufacturing of structural materials.
UPM's Product Development Laboratory	Equipment	Advanced design and manufacturing technologies for materializing the projects and prototypes of the course.

8. Other information

8.1. Other information about the subject

La asignatura se relaciona con el ODS 3, en lo relativo a diseño de implantes estructuralmente óptimos, y con el ODS9, por la relevancia de los procesos de diseño y fabricación avanzada tratados para múltiples industria y para innovar en el desarrollo de todo tipo de productos.