

## Course guide

### 330060 - CTM - Materials Science and Technology

Last modified: 03/06/2024

**Unit in charge:** Manresa School of Engineering  
**Teaching unit:** 750 - EMIT - Department of Mining, Industrial and ICT Engineering.

**Degree:** BACHELOR'S DEGREE IN CHEMICAL ENGINEERING (Syllabus 2009). (Compulsory subject).  
BACHELOR'S DEGREE IN ELECTRICAL ENGINEERING (Syllabus 2009). (Compulsory subject).  
BACHELOR'S DEGREE IN INDUSTRIAL ELECTRONICS AND AUTOMATIC CONTROL ENGINEERING (Syllabus 2009). (Compulsory subject).  
BACHELOR'S DEGREE IN MECHANICAL ENGINEERING (Syllabus 2009). (Compulsory subject).  
BACHELOR'S DEGREE IN ICT SYSTEMS ENGINEERING (Syllabus 2010). (Optional subject).  
BACHELOR'S DEGREE IN CHEMICAL ENGINEERING (Syllabus 2016). (Compulsory subject).  
BACHELOR'S DEGREE IN INDUSTRIAL ELECTRONICS AND AUTOMATIC CONTROL ENGINEERING (Syllabus 2016). (Compulsory subject).  
BACHELOR'S DEGREE IN MECHANICAL ENGINEERING (Syllabus 2016). (Compulsory subject).  
BACHELOR'S DEGREE IN MINERAL RESOURCE ENGINEERING AND MINERAL RECYCLING (Syllabus 2021). (Compulsory subject).  
BACHELOR'S DEGREE IN MINERAL RESOURCE ENGINEERING AND MINERAL RECYCLING / BACHELOR'S DEGREE IN ENVIRONMENTAL ENGINEERING (Syllabus 2024). (Compulsory subject).

**Academic year:** 2024    **ECTS Credits:** 6.0    **Languages:** Catalan

#### LECTURER

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**Coordinating lecturer:** MARIA NIUBÓ ESLAVA

**Others:** MARC ANTONI SOLER CONDE

#### DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

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**Specific:**

1. Knowledge of the fundamentals of materials science, technology and chemistry. An understanding of the relationship between the microstructure, synthesis or processing and properties of materials.

**Transversal:**

2. EFFICIENT ORAL AND WRITTEN COMMUNICATION - Level 1. Planning oral communication, answering questions properly and writing straightforward texts that are spelt correctly and are grammatically coherent.  
3. EFFECTIVE USE OF INFORMATION RESOURCES - Level 1. Identifying information needs. Using collections, premises and services that are available for designing and executing simple searches that are suited to the topic.

#### TEACHING METHODOLOGY

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Participatory lectures. Solving exercises and problems.

#### LEARNING OBJECTIVES OF THE SUBJECT

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On completion of the subject, students must be able to:

- Recognise and classify different types of materials.
- Interpret the properties and results of tests of materials.
- Assess factors that affect behaviour.
- Choose or rule out forming processes in view of the material and requirements.
- Predict possible problems and propose improvements to be carried out in the application of materials for a specific purpose.

## STUDY LOAD

Type	Hours	Percentage
Hours large group	45,0	30.00
Hours small group	15,0	10.00
Self study	90,0	60.00

**Total learning time:** 150 h

## CONTENTS

### 1. ATOMS, MOLECULES AND BONDS

**Description:**

- 1.1. Atomic bonding
- 1.2. Molecular bonding
- 1.3. Classification of materials according to their bonding type

**Specific objectives:**

- 1.1. Classify materials according to their composition.
- 1.2. Identify the dominant type of bond given the composition

**Full-or-part-time:** 2h

Theory classes: 2h

### 2. STRUCTURE OF MATERIALS

**Description:**

- 2.1. Crystal structure of solids. Basic concepts.
- 2.2. Crystal structure of metals. Single-crystal and polycrystalline.
- 2.3. Crystal structure of ceramics.
- 2.4. Crystal structure of polymers.

**Specific objectives:**

- 2.1. Classify materials according to their composition and structure.
- 2.2. Calculate the density of a crystalline metal or ceramic.
- 2.3. Describe the nature of polymer crystals.
- 2.4. Classify types of grain in metals.
- 2.5. Determine the directional component (isotropy) in view of the crystal structure.
- 2.6. Recognise the polymorphism and isomorphism of metals.

**Full-or-part-time:** 3h

Theory classes: 3h

### 3. IMPERFECTIONS IN THE CRYSTAL STRUCTURE

**Description:**

- 3.1. Imperfections in the structure of solids
- 3.2. Crystal imperfections of metals
- 3.3. Crystal imperfections of ceramics
- 3.4. Crystal imperfections of polymers
- 3.5. Non-crystalline structures
- 3.6. Microscopic observation, determination of grain size

**Specific objectives:**

- 3.1. Identify and classify crystal imperfections.
- 3.2. Calculate the density of interstitial and substitutional solid solutions.
- 3.3. Calculate the percentage of vacancies in a crystalline metal or ceramic.
- 3.4. Calculate the grain size index in a micrograph.
- 3.5. Describe the effect of crystalline imperfections on the plasticity of metals

**Related activities:**

A2, A7

**Full-or-part-time:** 2h

Theory classes: 2h

#### 4. MECHANICAL PROPERTIES AND TESTS

**Description:**

- 4.1. Mechanical properties of metals
- 4.2. Properties obtained in tension-compression tests
  - 4.2.1. Elastic regime
  - 4.2.2. Plastic regime
- 4.3. Hardness
  - 4.3.1. Rockwell
  - 4.3.2. Vickers
  - 4.3.3. Brinell
  - 4.3.4. Mohs
- 4.4. Fracture toughness. Impact toughness
- 4.5. Fatigue behaviour
- 4.6. Hot behaviour

**Specific objectives:**

- 4.1. Describe a tensile test.
- 4.2. Plot a stress-strain curve.
- 4.3. Using the data from a tensile test, calculate the following: elastic modulus, elastic limit, maximum strength, Poisson's ratio, elongation, necking coefficient and strain hardening exponent.
- 4.4. Using partial data, calculate the following: elastic modulus, elastic limit, maximum strength, Poisson's ratio, elongation, necking coefficient and strain hardening exponent.
- 4.5. Describe hardness tests HV, HB and HR.
- 4.6. Determine the differences, advantages and disadvantages of each one.
- 4.7. Calculate HB and HV from data or micrographs. Calculate maximum strength from HB.
- 4.8. Describe a fracture toughness test.
- 4.9. Calculate the critical stress for a given crack or the critical crack for a given level of stress.
- 4.10. Calculate the impact toughness.
- 4.11. Determine the ductile brittle transition temperature.
- 4.12. Describe a fatigue test.
- 4.13. Calculate the fatigue life in a test.
- 4.14. Calculate the fatigue limit, average stress and stress amplitude.
- 4.15. Describe a creep test.
- 4.16. Calculate creep duration and velocity.
- 4.17. Describe the evolution of a creep curve as a function of temperature and applied stress.

**Related activities:**

A2, A6

**Full-or-part-time:** 6h

Theory classes: 6h

## 5. DEFORMATION AND HARDENING MECHANISMS

### Description:

- 5.1. Dislocation and plastic deformation
- 5.2. Hardening mechanisms
- 5.3. Grain size hardening.
- 5.4. Precipitation hardening
- 5.5. Cold work hardening
- 5.6. Heat treatment hardening

### Specific objectives:

- 5.1. Describe the effect of crystal imperfections on the plasticity and movement of dislocations.
- 5.2. Calculate the elastic limit as a function of grain size.
- 5.3. Determine the effect of different types of alloys on mechanical behaviour.
- 5.4. Calculate the percent cold work. Calculate the elastic limit, maximum strength and elongation as a function of %CW.
- 5.5. Design the process of producing rolled steel from  $A_o$  to  $A_f$ , taking into account elastic limit, maximum strength, Poisson's ratio and elongation requirements.
- 5.6. Describe the annealing process.
- 5.7. Describe the fundamentals of heat treatment hardening.

### Related activities:

A2, A3, A6, A7

### Full-or-part-time: 3h

Theory classes: 3h

## 6. DIFFUSION

### Description:

- 6.1. Diffusion mechanisms
- 6.2. Fick's laws
- 6.3. Diffusion and treatment of materials (applications)

### Specific objectives:

- 6.1. Identify diffusion mechanisms and paths.
- 6.2. Calculate parameters with Fick's first and second laws.
- 6.3. Describe and recognise the main technological processes in which diffusion phenomena play a role.

### Full-or-part-time: 3h

Theory classes: 3h

## 7. PHASE DIAGRAMS

### Description:

- 7.1. Type of diagram and interpretation
- 7.2. Singular points
- 7.3. Fe-C diagram
  - 7.3.1. Classification of steels
  - 7.3.2. Classification of cast irons

### Specific objectives:

- 7.1. Interpret binary phase diagrams.
- 7.2. Calculate phases, compositions and quantities as a function of composition and temperature.
- 7.3. Describe the microstructural evolution of a cooling process.
- 7.4. Identify singular points.
- 7.5. Explain the technological importance of singular points.
- 7.6. Predict and calculate the structures in the Fe-C diagram.
- 7.7. Classify Fe-C alloys (steel and cast iron).
- 7.8. Describe their microstructure and possible behaviour.
- 7.9. Recognise the basic microstructures of Fe-C alloys.
- 7.10. Calculate the basic properties of normalised carbon steels.

### Related activities:

A2, A7

### Full-or-part-time: 3h

Theory classes: 3h

## 8. HEAT TREATMENTS

### Description:

- 8.1. Heat treatment of metals
- 8.2. Annealing
- 8.3. Quenching
- 8.4. Tempering
- 8.5. Precipitation and ageing
- 8.6. Thermochemical treatment of steels

### Specific objectives:

- 8.1. Interpret CCT and TTT curves.
- 8.2. Determine the heat treatment of a steel as a function of CCT and TTT curves.
- 8.3. Determine the annealing temperature.
- 8.4. Determine the microstructure of a carbon steel from the composition and treatment curve.
- 8.5. Choose the cooling medium for a heat treatment.
- 8.6. Classify types of hardening and predict the final mechanical behaviour.
- 8.7. Plot the curve of a precipitation and ageing treatment of a given alloy.
- 8.8. Determine which hardening treatment can be applied to different alloys and in which composition and temperature ranges.
- 8.9. Describe the main thermochemical treatments, their effects and their application conditions

### Related activities:

A3

### Full-or-part-time: 4h

Theory classes: 4h

## 9. ELECTRICAL AND MAGNETIC PROPERTIES

### Description:

- 9.1. Electrical behaviour and bonding
- 9.2. Conductors, dielectrics and semiconductors
- 9.3. Other electrical behaviours
- 9.4. Fundamentals of magnetism
- 9.5. Diamagnetism, paramagnetism and ferromagnetism

### Specific objectives:

- 9.1. Classify a material according to its electrical behaviour.
- 9.2. Calculate conductivity, load, intensity of the electric field, etc. for electrical materials.
- 9.4. Classify a material according to its magnetic behaviour.
- 9.2. Calculate permeability, field density, dissipated energy, etc. for magnetic materials.

**Full-or-part-time:** 3h

Theory classes: 3h

## 10. METALS

### Description:

- 10.1. Structure
- 10.2. Properties
- 10.3. Specific tests
- 10.4. Forming processes

### Specific objectives:

- 10.1. Describe the main characteristics, applications, advantages and disadvantages of metals.
- 10.2. Classify them according to different parameters.
- 10.3. Predict their properties from their structure and treatment.
- 10.4. Recognise the forming processes that are appropriate for these materials.

### Related activities:

A2

**Full-or-part-time:** 2h

Theory classes: 2h

## 11. CERAMICS

### Description:

- 11.1. Structure
- 11.2. Properties
- 11.3. Specific tests
- 11.4. Forming processes

### Specific objectives:

- 11.1. Describe the main characteristics, applications, advantages and disadvantages of ceramics.
- 11.2. Recognise crystal imperfections.
- 11.3. Determine parameters (melting temperature) in ternary diagrams.
- 11.4. Choose a refractory material for a given process.
- 11.5. Recognise the forming processes that are appropriate for the material.

**Full-or-part-time:** 2h

Theory classes: 2h

## 12. POLYMERS

### Description:

- 12.1. Structure
- 12.2. Properties
- 12.3. Specific tests
- 12.4. Forming processes

### Specific objectives:

- 12.1. Describe the main characteristics, applications, advantages and disadvantages of thermoplastics (TP), thermosets (TS) and elastomers (RB).
- 12.2. Classify a polymer as a TP, TS or RB.
- 12.3. Predict the degree of crystallinity.
- 12.4. Classify a copolymer.
- 12.5. Recognise additives and their effects.
- 12.6. Recognise the forming processes that are appropriate for these materials.

### Related activities:

A4

**Full-or-part-time:** 2h

Theory classes: 2h

## 13. COMPOSITES

### Description:

- 13.1. Structure
- 13.2. Properties
- 13.3. Specific tests
- 13.4. Forming processes

### Specific objectives:

- 13.1. Describe the main characteristics, applications, advantages and disadvantages of composites.
- 13.2. Classify them according to their matrix/reinforcement, type of reinforcement and directional behaviour.
- 13.3. Calculate their properties from the quantities of reinforcement and matrix.
- 13.4. Recognise the forming processes that are appropriate for these materials.

**Full-or-part-time:** 2h

Theory classes: 2h



## 14. CORROSION

### Description:

- 15.1. Chemical and electrochemical corrosion
- 15.2. Electrochemical cells
- 15.3. Corrosion velocity
- 15.4. Strategies for fighting and preventing corrosion

### Specific objectives:

- 15.1. Determine and classify electrochemical cells.
- 15.2. Identify the main anodic and cathodic reactions.
- 15.3. Design strategies for fighting corrosion in specific cases.
- 15.4. Calculate the corrosion velocity using Faraday's law.
- 15.5. Calculate a cathodic protection system.

### Related activities:

A4, A10

### Full-or-part-time: 2h

Theory classes: 2h

## ACTIVITIES

### 1. SIMULATION PRACTICAL

#### Description:

LABORATORY PRACTICAL

Students devise an example finite element simulation.

#### Specific objectives:

- Use a finite element software package.
- Interpret the results of a finite element simulation

#### Material:

Practicals book (available on the virtual campus)

#### Delivery:

At the end of the practical the corresponding assignment must be handed in.

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

### Full-or-part-time: 4h

Self study: 2h

Laboratory classes: 2h

## 2. METALLOGRAPHY PRACTICAL

### Description:

#### LABORATORY PRACTICAL

In this practical students learn various applications of metallographic microscopy techniques. In the first part, they must use the microscope correctly and identify the microstructure of various ferrous alloys. In the second part, they must calibrate an eyepiece with a scale and take various measurements. In the third part, they must determine the grain size index from a micrograph they have prepared beforehand. At the end of the practical the corresponding assignment must be handed in. A hardness test will also be carried out.

### Specific objectives:

On completion of the practical, students must be able to:

- Identify the basic microstructure of various ferrous alloys.
- Calibrate an eyepiece.
- Measure imprints of hardness and layers.
- Determine the grain size index.

### Material:

Practicals book (available on the virtual campus)

### Delivery:

At the end of the practical the corresponding assignment must be handed in.

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

Based on this practical and the corresponding topic, students must carry out Activity 4 (metallography problem).

### Full-or-part-time: 4h

Self study: 2h

Laboratory classes: 2h

## 3. HEAT TREATMENT PRACTICAL

### Description:

#### LABORATORY PRACTICAL

Students carry out hardening and tempering heat treatments. They then compare the microstructure and hardness with an annealed sample.

### Specific objectives:

On completion of the practical, students must be able to:

- Determine treatment temperatures and types of cooling.
- Relate microstructures to properties and types of treatment.
- Use basic sample preparation techniques.

### Material:

Practicals book (available on the virtual campus)

### Delivery:

At the end of the practical the corresponding assignment must be handed in.

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

### Full-or-part-time: 4h

Self study: 2h

Laboratory classes: 2h

#### 4. CORROSION PRACTICAL

**Description:**

LABORATORY PRACTICAL

Students determine a galvanic salt water series, prepare various types of electrochemical cells and carry out the electrochemical deposition of a metal.

**Specific objectives:**

On completion of the practical, students must be able to:

Determine a galvanic series.

Classify a corrosion cell.

Calculate the theoretical weight of electrolytic coating and performance in the practical case

**Material:**

Practicals book (available on the virtual campus)

**Delivery:**

At the end of the practical the corresponding assignment must be handed in.

Carrying out the practical validates the result of the questionnaire (Activity 9).

**Full-or-part-time:** 4h

Self study: 2h

Laboratory classes: 2h

#### 5. MECHANICAL TEST PRACTICAL

**Description:**

LABORATORY PRACTICAL

Students carry out tensile and flexural strength impact tests on various materials.

**Specific objectives:**

On completion of the activity, students must be able to:

Carry out a tensile test.

Determine the main properties of materials.

Carry out and interpret a Charpy impact test.

**Material:**

Practicals book (available on the virtual campus)

**Delivery:**

At the end of the practical the corresponding assignment must be handed in.

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

**Full-or-part-time:** 10h

Self study: 8h

Laboratory classes: 2h

## 6. TENSILE TEST

### Description:

Students are given a file containing real data of a tensile test and they must process them to carry out and hand in a report that follows the guidelines published in the virtual campus.

### Specific objectives:

On completion of the activity, students must be able to:

Calculate the strength, elastic limit, ductility, elastic modulus and hardening coefficient of a metal from tensile test data.

### Material:

Video tutorial in UPCommons

### Delivery:

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

### Full-or-part-time: 6h

Self study: 3h

Guided activities: 3h

## 7. IMAGE ANALYSIS

### Description:

Students are sent a file containing various micrographs. Students are asked to quantify the phases present and take measurements using the GIMP image analysis software.

### Specific objectives:

On completion of the activity, students must be able to:

- Quantify phases using image analysis.
- Take measurements using image analysis.
- Apply the Hall-Petch law.

### Material:

Practicals book (available on the virtual campus)

Software available at <http://www.softcatala.org/kiwi/Rebost:GIMP>

Video tutorials in UPCommons

### Delivery:

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

### Full-or-part-time: 3h

Self study: 3h

## 8. METALLOGRAPHY

### Description:

Students are sent a micrograph and they must calculate the grain size index and then the elastic limit of a metal using the Hall-Petch relation.

### Specific objectives:

On completion of the activity, students must be able to:

- Determine the grain size index and find the average grain diameter.
- Apply the Hall-Petch law.

### Material:

Practicals book (available on the virtual campus)

### Delivery:

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

### Full-or-part-time: 3h

Self study: 3h

## 9. CORROSION PRACTICAL QUESTIONNAIRE

### Description:

Questionnaire to assess progress in the corrosion practical

### Specific objectives:

On completion of the activity, students must be able to:

Recognise corrosion cells and classify them.

Predict the corrosion behaviour from a galvanic series. Calculate a galvanic anode.

### Material:

Practicals book (available on the virtual campus)

### Delivery:

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide

### Full-or-part-time: 3h

Self study: 3h

## 10. PROGRESS TEST I

**Description:**

Written test in which students must demonstrate their understanding of the knowledge they have acquired on the topics explained so far.

**Specific objectives:**

For students to consolidate the knowledge acquired so far.

**Delivery:**

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

**Full-or-part-time:** 21h

Self study: 18h

Theory classes: 3h

## 11. INTEGRATION TEST

**Description:**

Written test in which students must demonstrate their understanding of the knowledge they have acquired on the topics explained so far. In the test they will have to relate their knowledge of various topics.

**Specific objectives:**

For students to consolidate the knowledge acquired so far and for them to hone their ability to relate topics to one another.

**Delivery:**

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

**Full-or-part-time:** 31h

Self study: 28h

Theory classes: 3h

## 12. PHASE DIAGRAM QUESTIONNAIRE

**Description:**

Questionnaire to assess progress in the corrosion practical

**Specific objectives:**

For students to consolidate their knowledge of phase diagrams.

**Material:**

Class notes in the virtual campus

**Delivery:**

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide

**Full-or-part-time:** 3h

Self study: 3h

### 13. EFFECTIVE USE OF INFORMATION RESOURCES

**Description:**

For students to find books, journals and articles in the catalogue and search engines.

For students to become familiar with the services offered by UPC libraries and the Manresa University Campus Library in particular.

**Specific objectives:**

For students to find books, journals and articles in the catalogue and search engines.

For students to become familiar with the services offered by UPC libraries and the Manresa University Campus Library in particular.

**Material:**

Class notes in the virtual campus

**Delivery:**

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

**Full-or-part-time:** 3h 30m

Self study: 1h 30m

Laboratory classes: 2h

### 14. EFFECTIVE USE OF INFORMATION RESOURCES ASSIGNMENT

**Description:**

Bibliographic research assignment

**Specific objectives:**

For students to find information on a topic in three different formats (book, web page and article). For students to cite the sources they find correctly.

**Material:**

Class notes in the virtual campus

**Delivery:**

The assessment of the assignment and the other activities are part of the assessment as specified in the corresponding section of the course guide.

**Full-or-part-time:** 2h

Self study: 2h

## GRADING SYSTEM

Marks are calculated using the following formula:

$$N = N_t \cdot 0.80 + N_p \cdot 0.20$$

where N is the final mark, N<sub>t</sub> the theory mark and N<sub>p</sub> the mark for the practicals. The latter two are calculated in the following way:

$$N_t = A_{10} \cdot 0.50 + A_{11} \cdot 0.50$$

$$N_p = (A_{14} \cdot 0.17 + A_6 \cdot 0.27 + A_8 \cdot 0.20 + A_{12} \cdot 0.16 + A_7 \cdot 0.20) \cdot L$$

A<sub>10</sub>, A<sub>11</sub>, etc. are the marks for activities 10, 11, etc.

L is the mark for the laboratory practicals.

Activity A<sub>14</sub> assess progress on the effective use of information resources competency.



## EXAMINATION RULES.

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All the activities are individual unless otherwise stated. To carry out the practicals students must have passed the questionnaire published in the virtual campus beforehand.

All reports must be submitted in ISO 9000 format.

They must be students' original work. Copying their content will be punished with a mark of Fail for the activity and the subject.

## BIBLIOGRAPHY

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### Basic:

- Callister, William D.; Rethwisch, David G. Ciencia e ingeniería de los materiales [on line]. 2ª ed. Barcelona: Reverté, 2016 [ Consultation: 10/06/2022 ]. Available on: [https://search-ebscohost-com.recursos.biblioteca.upc.edu/login.aspx?direct=true&AuthType=ip,uid&db=nlebk&AN=2616389&site=ehost-live&ebv=EB&ppid=pp\\_a](https://search-ebscohost-com.recursos.biblioteca.upc.edu/login.aspx?direct=true&AuthType=ip,uid&db=nlebk&AN=2616389&site=ehost-live&ebv=EB&ppid=pp_a). ISBN 9788429172515.
- Van Vlack, Lawrence H. Elements of materials science and engineering. 6th ed. Reading, Massachusetts: Addison-Wesley, 1989. ISBN 0201528223.

### Complementary:

- Askeland, Donald R.; Wright, Wendelin J. Ciencia e ingeniería de los materiales. 7a. México: Cengages Learning, 2021. ISBN 9786075260624.
- Smith, W.F.; Hashemi, J.; Murrieta, J.E. Fundamentos de la ciencia e ingeniería de los materiales. 7a ed. México: McGraw-Hill, 2023. ISBN 9781456294878.
- Shackelford, James F. Introducción a la ciencia de materiales para ingenieros [on line]. 7ª ed. Madrid: Pearson educación, 2010 [ Consultation: 02/06/2022 ]. Available on: [https://www-ingebook-com.recursos.biblioteca.upc.edu/ib/NPcd/IB\\_BooksVis?cod\\_primaria=1000187&codigo\\_libro=1258](https://www-ingebook-com.recursos.biblioteca.upc.edu/ib/NPcd/IB_BooksVis?cod_primaria=1000187&codigo_libro=1258). ISBN 9788483226599.
- Flinn, Richard A.; Trojan, Paul K. Materiales de ingeniería y sus aplicaciones. 3ª ed. Bogotá: McGraw-Hill, 1989. ISBN 958600032X.

## RESOURCES

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### Other resources:

Audiovisual material

Video: Tutorial d'anàlisi d'imatge metal·logràfica amb EL GIMP. Available in UPCommons

Computer material

ANSYS: available in the computer rooms

GIMP. Free software available at <http://www.softcatala.cat/>. Available in the computer rooms

Website

Matter

Jominy: [http://www.matter.org.uk/steelmatter/metallurgy/7\\_1\\_1](http://www.matter.org.uk/steelmatter/metallurgy/7_1_1)

Hall-Petch: <http://aluminium.matter.org.uk/content/html/eng/default.asp?catid=64&pageid=1000314345> /> Charpy: <http://www.steeluniversity.org/content/html/eng/default.asp?catid=151&pageid=208127192> />