Course offered for the PhD program
in Civil, Chemical and Environmental Engineering
Curriculum in Structural and Geotechnical Engineering, Mechanics and Materials
a.a. 2026/2027
(course open to students from other PhD cycles or programs)

1. Title
Concrete Thermo-Mechanics

2. Course Description
The course provides an introduction to the thermo-mechanical behaviour of concrete and cementitious composites, with particular attention to heat transfer, temperature-dependent material properties, thermal stresses, and coupled thermo-mechanical modelling.

Main topics:
Fundamentals of heat transfer in concrete and cementitious materials
- Sensible and latent heat
- Thermal conductivity, heat capacity and density
- Heat diffusion in solids
- Temperature evolution in concrete elements
- Initial and boundary conditions for thermal problems
- Thermal gradients in massive and slender concrete structures

Thermal Energy Storage and phase change phenomena
- Basic theory of phase change phenomena
- Sensible and latent thermal energy storage
- Phase Change Materials in cementitious composites
- Stefan Problem
- Enthalpy-Based Method
- Apparent Calorific Capacity Method
- Heat Source Method
- Numerical treatment of melting and solidification processes

Thermo-mechanical behaviour of concrete
- Thermal strains and restrained thermal deformations
- Thermal stresses in concrete structures
- Temperature-dependent mechanical properties
- Evolution of strength and stiffness with temperature
- Cracking induced by thermal gradients
- Early-age thermal effects and restrained shrinkage
- Thermo-mechanical response of cementitious composites

Finite Element Method approach
- Basic FEM formulation for heat transfer problems
- 1D, 2D and 3D finite elements
- Shape functions
- Capacity and conductivity matrices
- Time integration schemes
- Coupled thermo-mechanical formulation
- Interpretation of numerical results

Numerical implementation and practical examples
- Implementation of heat transfer problems in Octave/Matlab or similar tools
- Implementation of phase change phenomena
- Examples of transient heat transfer problems
- Examples of thermal stress analysis
- Simplified modelling of concrete elements subjected to thermal gradients

FEM simulations in Abaqus or similar software

Heat transfer examples in 1D, 2D and 3D
Thermo-mechanical analysis of concrete elements
Examples involving phase change phenomena
Numerical solution of benchmark problems, including the Stefan Problem
Applications to cementitious composites, massive concrete elements, and thermal energy storage systems

3. Course Organization

The course is organized through frontal lessons, numerical demonstrations, and practical classes in the laboratory. Students will be introduced to theoretical concepts and then guided through numerical examples and finite element simulations. Practical activities will focus on the implementation and interpretation of thermal and thermo-mechanical models for concrete and cementitious composites.

4. Teacher

Prof. Antonio Caggiano (antonio.caggiano@unige.it)
Dr. Ignacio Peralta (ignacio.peralta@edu.unige.it)

5. Duration and Credits

20 hours, 4 CFU

6. Activation Mode and Teaching Period

Period: **xxx – xxx 2027**.
Frontal lessons and practical classes.
The detailed timetable will be communicated before the beginning of the course.

7. Deadline for Registration

End of **xxx 2027**.

Application by email to the teacher:
antonio.caggiano@unige.it

8. Final Exam

The final exam will consist of a practical numerical assignment and a short oral discussion.
Possible activities include:

- Application of a FEM code, such as Abaqus or similar, to solve a 3D thermo-mechanical problem in concrete.
- Application of a FEM code, such as Abaqus or similar, to solve a heat transfer or phase change problem.
- Numerical solution of a Stefan Problem or an equivalent benchmark case.
- Interpretation and discussion of temperature fields, thermal gradients, thermal stresses, and possible cracking mechanisms.

The final evaluation will consider the correctness of the numerical model, the interpretation of the results, and the student’s ability to discuss the physical meaning of the thermo-mechanical response.