I: Early Age Concrete Characterization designed for the nuclear power plant of the Vercors Project

Influence of the curing conditions on the evolution of the free and restraint deformations

Context of the master thesis

As part of EDF’s continuous effort on the safety and life extensions to its fleet of Nuclear Power Plants, an experimental **mock-up of a reactor containment building at 1/3 scale** is being built at Renardières near Paris and will be completed in the first half of 2015. The mock-up is finely instrumented so that its behavior is monitored from the beginning of the construction. More than **500 sensors and 2 km of fiber optic cables** are to be positioned in the concrete and both on the rebars and on the prestressing cables. During the construction, measurements will be realized just after concreting during time intervals of one hour. During the research program, several measurements will be collected every day on each sensor. Hundreds of samples of concrete will be prepared and tested to determine their material behaviors and parameters, including modulii and strength, drying, shrinkage, creep, and permeability. The **first objective** of the project is to study the behavior at early age of the structure. **VeRCoRs, it is:**

- A double wall containment (H=30m, Ø=16m),
- 5000 t of concrete,
- 500 sensors and over 1000 sample concrete test specimens,
- 1 year of construction,
- A research program lasting over 10 years bringing international Experts and laboratories.

The steps of construction of this mock-up can induce a cracking risk in the concrete structure when the deformations are restraint at early age which induces tensile stresses in concrete. If their amplitude is too large, cracks appear at early age. Creep plays an important role in the determination of the effective stress. It is important to consider the creep at early age for the design of concrete structures with restraint deformations. However, it is still difficult to assess creep at early age in concrete, especially in tension. A review of the literature shows that there is no consensus on the influence of the state of stress in compression or in tension upon creep. **The effect of temperature and moisture on the creep at early age has not clearly been established in previous research.** To monitor the creep of the Vercors project concrete, 3 types of experimental devices are available in BATir lab: a TSTM machine, a set of two tensile creep rigs and a set of 16 compressive creep rigs.
References

Objectives of the master thesis
Two students are very welcome for this master thesis. The main goal of this master thesis consists in studying the early age behavior of the concrete designed for the nuclear power plant of the Vercors project by means of the characterization of the mechanical properties: tensile creep, compression creep, Young’s modulus, strength by using existing tools available in the BATir-LGC lab in various conditions (temperature, applied loads,…). On basis of this data base, numerical simulations will be done in 1D to better understand the effect of the studied parameters on the cracking sensitivity of such concrete structure in practical situations. A comparison between numerical results will be also done with the experimental results obtained with the TSTM machine. It is a part of an international COST Action (www.tu1404.eu) project that the Laboratory of Civil Engineering at ULB is chairing together with the University of Minho in Portugal.

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Working language
English/French

Student profile
Civil Engineering/Architectural Engineering

Prerequisites/special skills (optional)
The student must have an interest in Concrete materials and structures, basic programming skills in Matlab and an interest in experimental testing.
II: Effect of mix design on the early-age properties and mechanical strength of alkali activated concrete

Context of the master thesis

Alkali activated concrete corresponds to a class of aluminosilicate materials formed typically by activation of a fine solid precursor such as coal combustion fly ash, calcined clays and metallurgical slags (i.e. granulated blast furnace slag) with concentrated alkali hydroxide or alkali silicate solution (i.e. sodium hydroxide and sodium silicate) to stimulate minerals dissolution and to create a binder matrix for setting and hardening. In the last two decades this new type of concrete has been developed and investigated as one of the key alternatives to Portland cement concrete for the development of more durable, sustainable and low-CO2 construction and building materials with reduced environmental footprint. Alkali activated concrete offers several potential advantages including higher rate of strength development, lower permeability, higher resistance to chemical attack, and lower rate of heat release than Portland cement concrete. Therefore, it is rapidly growing both with technological developments in structural, civil engineering and niche applications, and with numerous scientific works.

Alkali activated concrete is different from Portland cement concrete because of setting and hardening process controlled by the hydration reactions including geopolymer network formation. Moreover, calcium hydroxide does not form due to the low Ca/Si. This structural and chemical difference, however, brings along a crucial shortcoming for the alkali activated concrete, which is rapid hardening resulting in very short setting times and shrinkage microcracking. Autogeneous shrinkage which is the result of the chemical shrinkage occurring during the hydration process could be at the origin of this crack formation.

References


Objectives of the master thesis

In this thesis, early-age and mechanical properties of alkali activated concrete in various compositions using fly ash and granulated blast furnace slag will be studied. The aim is to investigate the influence of mix design proportioning (fly ash to slag ratio, type and molarity of alkali solution and solid to alkali ratio) on the hydration, autogeneous shrinkage, fresh properties (setting, flow, slump, air content) and hardened properties (compressive, bending and split tensile strength, E-modulus) of concrete using standard test methods. Early-age autogeneous shrinkage deformation in mortar and concrete mixes will be followed continuously and evaluated with respect to different binder compositions.
Early-age hydration will be followed up using continuous monitoring techniques of ultrasonic p-wave transmission and isothermal calorimetry. The results will be compared with those of Portland cement concrete. This thesis study requires a combination of theoretical study and laboratory work that will involve a series of laboratory tests on mortars and concrete. This thesis work will contribute to the field of sustainable construction materials and sustainable development where reuse and recycling of industrial residues is the key.

Two students are very welcome for this master thesis. All the experimental technics are available at the Laboratory of Civil Engineering at ULB. It will involve also a set of meetings (and a limited number of experimental tests) at KUL for exchanges and discussions about the mix design and the microstructure evaluation of these innovative materials.

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III: Modelling the heat of hydration of Portland cement under ambient conditions

Context of the master thesis
Hydration of cement is an exothermic reaction, and thus emits a certain amount of heat during the process. Measuring and monitoring the heat release gives an insight into the hydration process like degree of hydration. The evolution of mechanical strength of concrete depends mainly on its degree of hydration. A concrete cube reaches its maximum strength when degree of hydration is 100%. If the constituents of cement is known and its individual heat of hydration is known, degree of hydration can be predicted from the total heat evolved till that instant. The heat of hydration could be used to predict both the early age and later age properties of concrete.

While we can use simple experimental setups to predict the heat of hydration in the laboratory scale it would be very difficult to measure the same on field. Computational modelling comes handy in these cases. The outputs from the model would be very useful for design engineers, especially to construct massive structures such as a dam. Also it could be used to design concrete structures with a more realistic strength values which incorporates the ambient temperature conditions.

References

Objectives of the master thesis
In this thesis, it is expected to formulate a model to predict the heat of hydration of Ordinary Portland cement (OPC) for various periods of hydration, and subject to different ambient temperature conditions. Using a combination of laboratory techniques like isothermal calorimetry and semi-adiabatic calorimetry and by modelling approach, it is possible to find the heat of hydration at various temperatures. While isothermal calorimeter will record the heat release at constant temperature, semi adiabatic calorimeter will record the heat release in a semi-adiabatic condition (almost insulated condition). The current available theoretical models could be used and modified to predict the heat of hydration on a more realistic level.
Two students are very welcome for this master thesis. All the experimental technics are available at the Laboratory of Civil Engineering at ULB. It will involve also a set of meetings at KUL for exchanges and discussions about the numerical part.

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**Working language**

English/French

**Student profile**

Civil Engineering/Architectural Engineering

**Prerequisites/special skills (optional)**

*The two students must have an interest in Concrete material, in experimental testing and numerical modeling and also like carrying out a collaborative work within two labs.*
## IV: Early age microstructural development of cement mortars using ultrasonic pulse velocity

### Context of the master thesis

Ultrasonic pulse velocity (UPV) is a great tool which could be used for a variety of applications. It is mainly used as a non-destructive tool to predict the strength of concrete. With the latest advancements in the technology and by using modelling approach more data could be obtained from the UPV such as the setting time, modulus of elasticity, porosity etc. UPV is more suited to follow the early age microstructural development as it gives continuous measurements of changes in microstructure from fresh state to hardened state. Additionally conventional methods would need a tedious process of sample preparation without disturbing the microstructure and accounting for the continuous high reaction rates at the early ages.

UPV depends mainly on the density and elastic modulus of the material. When cement hydrates, the reaction products will be having a different density and elastic modulus than the reactants. And they fill up the voids in the microstructure reducing the porosity in the microstructure of cement matrix over time. Homogenization of the cement mortars or cement pastes is the key for the further advancement in this technique which could be used using the existing models.

### References


### Objectives of the master thesis

This project aims at using the UPV technology to follow the early age microstructural developments by means of experimental results and modelling. The technique will be calibrated and validated using the combination of complementary methods to determine the porosity and to follow the hydration reactions. Existing microstructural models would be used to model the microstructure.
Two students are very welcome for this master thesis. All the experimental technics are available at the Laboratory of Civil Engineering at ULB and at KUL. It will involve also a set of meetings (and a limited number of experimental tests) at KUL for exchanges and discussions about the experimental and numerical parts of this study.

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V: Autogenous shrinkage in alkali activated binders

Context of the master thesis

Alkali activated binders are one of the most promising replacement for Portland cement to ensure sustainability of construction with concrete applications. Alkali activated binders are generally supplementary cementing materials such as ground granulated blast furnace slag (GGBFS), fly ash, calcined clay etc. mixed with high concentration alkali such as NaOH. The main advantage of such a binder system lies in the fact that these materials would need far less energy to process compared to the production of Portland cement, and there is a significant reduction in the amount of carbon dioxide that is been emitted to the atmosphere. Additionally, slag and fly ash are by-products from the industry and using them would be advantageous in the sense of recycling and utilization of industrial by-products in high volumes in construction applications. Therefore, this technology contributes significantly to the sustainable development of construction.

Autogenous shrinkage is one of main issues associated with this binder system. This is primarily because of the hydration products, porosity, curing temperature, etc. This thesis intends to identify such factors that contribute to the significant development of autogenous shrinkage. Also it would be in the scope of the project to find remedial measures which could be helpful in reducing the autogenous shrinkage. The tests will be primarily on mortar and concrete.

References


Objectives of the master thesis

This thesis study requires a combination of theoretical study and laboratory work that will involve a series of analytical techniques on binders and testing methods on mortars. This thesis work will contribute to the field of sustainable construction materials, which is ultimately targeting reduced-clinker and even clinker-free binders within the global perspectives of sustainable development where reuse and recycling of waste is the key.
Two students are very welcome for this master thesis. All the experimental technics are available at the Laboratory of Civil Engineering at ULB. It will involve also a set of meetings (and a limited number of experimental tests) at KUL for exchanges and discussions about the mix design and the microstructure evaluation of these innovative materials.

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