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# Exercise 1: Part A - Calculating heat release from semi-adiabatic calorimetry test results, Part B - Maturity for different temperature histories

Part A - Heat of hydration. A semi-adiabatic calorimetry test was carried out on two different materials: a conventional concrete (256 kg/m³ of CEM I 32.5 N, 77 kg/m³ of fly ash, W/B=0.45, and an Ultra High Performance Fibrated concrete (1410 kg/m³ of CEM I 52.5 R, 367 kg/m³ of silica fume, W/B=0.131. The detailed compositions of these 2 materials are given in the following table:

| | | Concrete 1 | | UHPFRC | |
|---|---|---|---|---|---|
| Component | $Cv_i$ [kJ/kg.K] | $m_i$ [kg/m³] | $Cv_i*m_i$ | $m_i$ [kg/m³] | $Cv_i*m_i$ |
| Cement | 0.76 | 256 | | 1410 | |
| Additions | 0.73 | 77 | | 367 | |
| Aggregates | 0.84 | 2008 | | 80 | |
| Water | 4.19 | 128 | | 200 | |
| Superplasticizer | 4.19 | 2.68 | | 33 | |
| Steel fibers | 0.434 | | | 707 | |
| | | 2472 | | 2797 | |
| | | ρ [kg/m³] | Cv[kJ/m³.K] | ρ [kg/m³] | Cv[kJ/m³.K] |

Test results (semi-adiabatic temperature measurements) are given in Appendix 3.

1. Calculate the heat capacity $\mathbf{Cv} = \sum_{\mathbf{i}} \mathbf{C_{vi}} \cdot \mathbf{m_i}$ of the 2 materials by completing Table 1.
2. Calculate the total heat $H_t$ released at 7 days by the 2 materials from the adiabatic temperature evolution given in Appendix 3 and the models given in Appendix 1.
3. Calculate the apparent total heat of hydration $H_{ciment}$ at 7 d of cements for the 2 materials, using the model for compound binders given in Appendix 2. Discuss the results obtained.

## Part B – Maturity

Consider a concrete made with CEM I 42.5 N cement.

4. What is the activation energy of this concrete?
5. What would be the maturity at an age of 28 days of this concrete in the following thermal curing cases (the effect of heat of hydration will be neglected):

- T = 5°C from t = 0 to 28 d
- T = 20°C from t = 0 to 28 d
- T = 40°C from t = 0 to 28 d
- T = 5°C from t = 0 to 3 d followed by T = 20°C from t = 4 to 28 d.

6. Discuss the results.

## Appendix 1: Modeling the semi-adiabatic calorimetry test

The test is modeled by considering a point heat source surrounded by thermal insulation. The internal temperature gradient term is neglected. The heat transfer equation is composed of three terms: the first characterizes the storage capacity of the heat produced, the second represents the source of the hydration heat released, while the last term expresses the thermal losses of the measurement system since the test is not perfectly insulated.

$$(C_{cal} + c_v V)\frac{dT}{dt} - \frac{dHydr(M(t))}{dt}V = -\pi_T S(T(t) - T_e(t)) \qquad (1)$$

Where
- $c_v$: Heat capacity of concrete (kJ/°K.m$^3$)
- $C_{cal}$: Calorimeter heat capacity (kJ/°K)
- V: Specimen volume (m$^3$)
- S: Total developed surface area of the specimen (m$^2$)
- $\pi_T$: Heat loss coefficient (W/m$^2$.K)
- T: Core temperature (°C)
- $T_e$: Ambiant temperature (°C)
- Hydr (M(t)): Hydration heat released by the concrete (kJ/°K.m$^3$)
- t: Time (s)
- M (t): Maturity (s)

Numerical integration of equation (1) allows us to find the adiabatic temperature rise $T_{adiab}$ (t) (without losses) from the temperature evolution measured during the semi-adiabatic test. The heat released at time t is given directly by the following equation:

$$\Delta Tadiab(t) = \frac{H_t(t)}{Cv} \qquad (2)$$

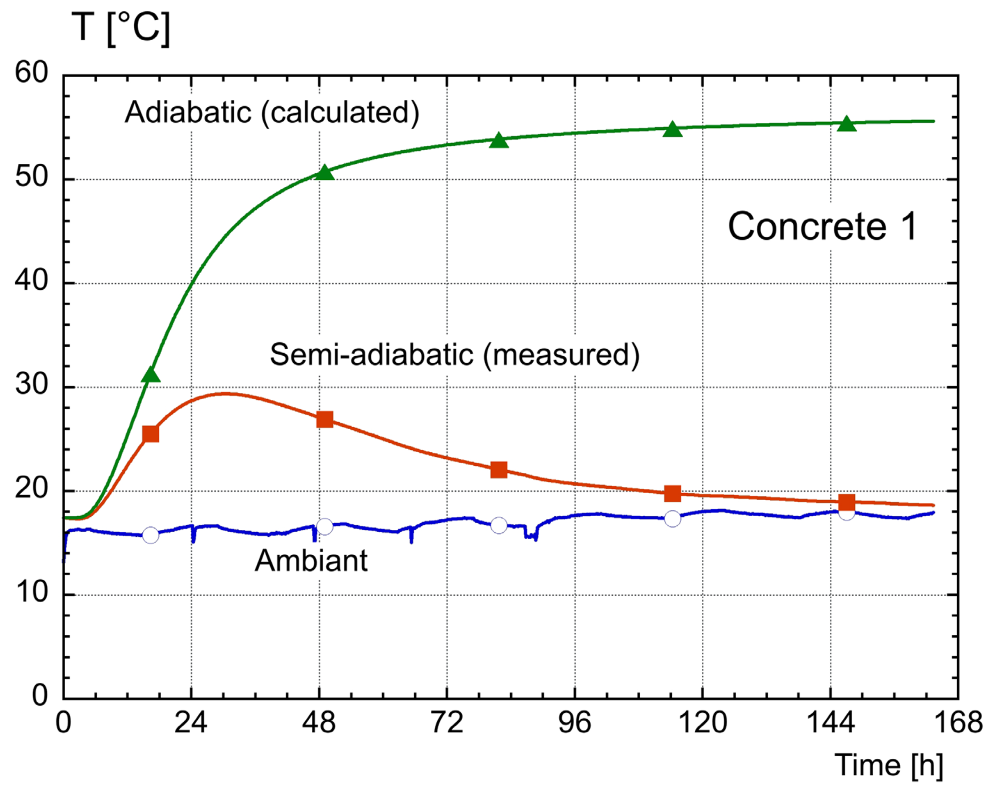
## Appendix 2: Heat of hydration of compound binders

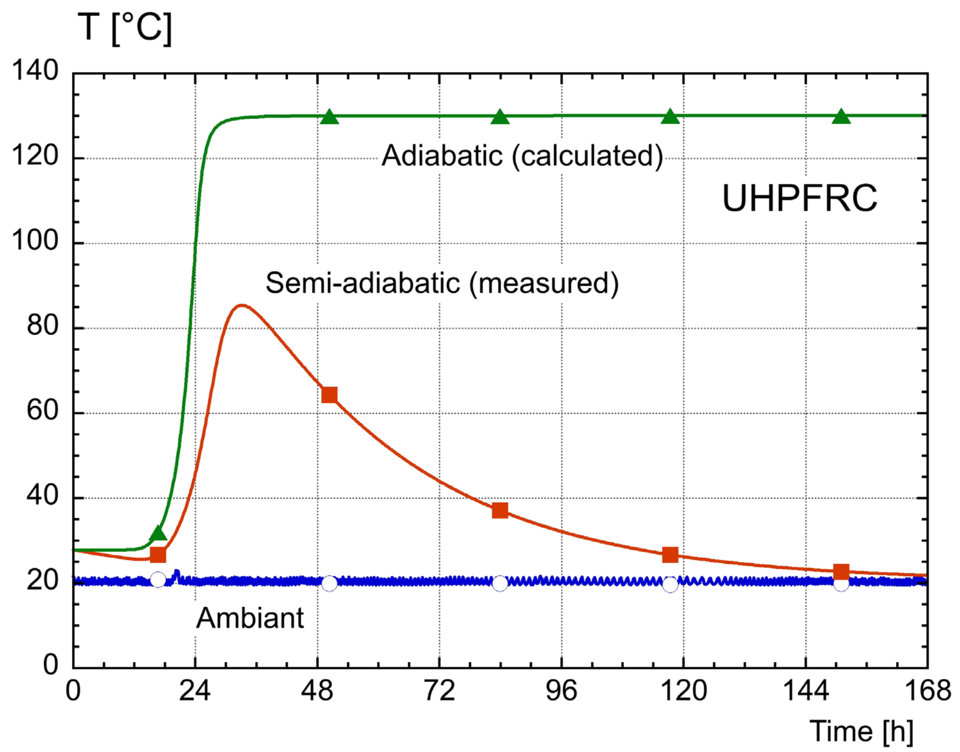
$$H_T = H_{cement} \cdot m_{cement} + H_{addition} \cdot m_{addition} \qquad \text{Neville (2000)} \qquad (3)$$

where:
- $H_T$: Total heat of hydration released by concrete (kJ/m$^3$)
- $H_{addition}$: Total heat of hydration released by mineral addition (kJ/kg),
- $H_{cement}$: Total heat of hydration released by cement (kJ/kg)
- $m_{cement}$: Cement mass (kg/m$^3$)
- $m_{addition}$: Mass of mineral addition (kg/m$^3$).

It is generally accepted that for fly ash the total heat released is half that released by the cement or around 150 J/g (kJ/kg), and that for silica fume it is twice that released by the cement used.

## Appendix 3: Test results and calculated adiabatic temperature trends

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