E X A M

Course code:	**BYG405**
Course name:	**High performance materials**
Date:	December 2, 2016
Duration:	4 hours
Number of pages incl. front page:	8
Resources allowed:	Calculator and a bright and well-trimmed brain
Notes:	This assignment comprises two parts; Part 1: Concrete and Part 2: Composites. **Please separate these two parts on separate sheets.**

PART 1 - CONCRETE

Task 1 (recommended time consumption up to 60 min)

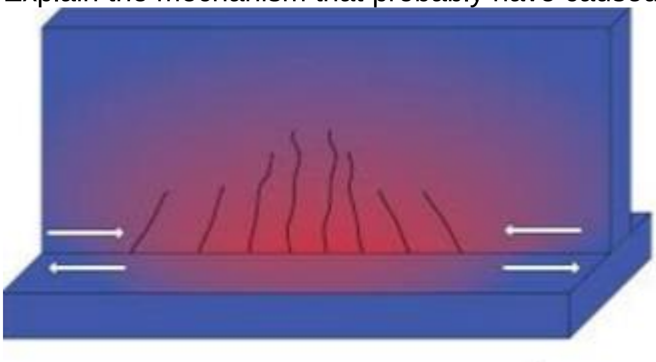
a. Explain two principles for measuring “set time” of hardening concrete.

b. Explain briefly Power’s model of hydration.

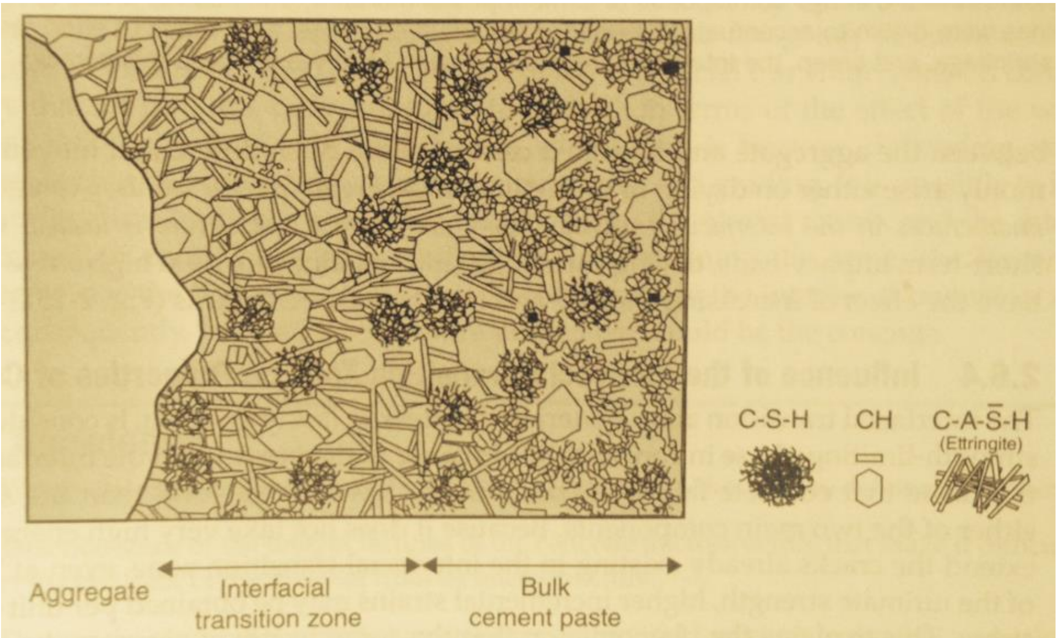
c. According to Power’s model of hydration: Calculate the volume of micropores for a concrete made with 400kg of cement and W/C-ratio=0.3, at a hydration level of 80%. (Density of cement is 3125kg/m3).

d. Explain the mechanism for autogenous shrinkage in concrete. Also explain why autogenous shrinkage tends to increase when high-quality pozzolans are included.

e. Explain the mechanism that probably have caused the wall on the figure to crack.



f. Explain as much as possible of the mechanical properties (compressive strength) as you can, based on the figure below.



g. Describe the pozzolan reaction of concrete. Also explain why the use of high quality pozzolans might improve the durability of concrete (ref to the figure above).

h. Use the tables below (from NS-EN 197-1) to extract as much information as possible from the cement denotation EN197-1-CEM III A 52,5N.

Strength class	Compressive strength (MPa)					Initial setting time (min)	Soundness (Expansion) (mm)
	Early strength			Standard strength			
	1 day	2 days	7 days	28 days			
32,5 N	-	-	≥ 16	≥ 32,5	≤ 52,5	≥ 75	≤ 10
32,5 R	-	≥ 10	-				
32,5 RR*	≥ 10	≥ 20	-				
42,5 N	-	≥ 10	-	≥ 42,5	≤ 62,5	≥ 60	
42,5 R	-	≥ 20	-				
42,5 RR*	≥ 20	≥ 30	-				
52,5 N	-	≥ 20	-	≥ 52,5	-	≥ 45	
52,5 R	-	≥ 30	-				

Main types	Product notation		Composition (proportion by mass %)				
			Main constituents				Minor additional constituents
			Clinker	Blastfurnace slag (S)	Silica fume (D)	Fly ash siliceous (V)	
CEM I	Portland cement	CEM I	95-100	-	-	-	0-5
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20	-	-	0-5
		CEM II/B-S	65-79	21-35	-	-	0-5
	Portland-silica fume cement	CEM II/A-D	90-94	-	6-10	-	0-5
	Portland-fly ash cement	CEM II/A-V	80-94	-	-	6-20	0-5
		CEM II/B-V	65-79	-	-	21-35	0-5
CEM III	Blastfurnace cement	CEM III/A	35-65	35-65	-	-	0-5

i. According to the particle-matrix method (PMM) for proportioning concrete:
    - How is the matrix phase of the concrete defined?
    - Explain the meaning of the expression “matrix dominated” concrete
    - Mention one important shortcoming of the PMM.

Task 2 (recommended time consumption up to 60 min)

a. The class has executed a lab project, consisting of two parts. For each of the parts, the massive amounts of results originating from all the groups has been made collectively available to all students. All these results should be considered to be from one common project. Explain the design of the UHPC-part of the project (organization, variables, measured parameters and execution – including measures to reduce effects of variations.)

b. Explain:
    - Principles for statistical treatment of the results from this kind of lab experiments (how and why)
    - What can be learned from the results prior to statistical handling?

c. You were meant to base your analysis of the results on a few scientific articles identified at suitable sources on the internet. Reproduce the main outlines from the articles that you used for the report (UHPC-part).

d. Explain the main parts of the analysis and conclusions from your own report (UHPC-part).

e. Suggest changes to the lab program, which would improve your learning outcome. Justify your suggestions.

PART 2 - COMPOSITE MATERIALS (recommended time consumption up to 120 min)

Task 1: General knowledge Quiz on composite materials

a) Mention some of the advantages by using polymer composite materials. Give some examples where composites successfully have been used and explain why composites were used in these applications?

b) Mention some of the disadvantages by using polymer composite materials. Give one example and describe why composites can not/should not be used in this application?

c) What main factors control the mechanical properties of a fiber reinforced composite material?

d) You are designing a composite structure subjected to extreme fatigue loads. You can choose glass, carbon or Kevlar fibers, and polyester, vinylester or epoxy resins. What is the best combination?

e) What is the function of the resin part in a fiber reinforced composite?

f) Derive the stiffness transverse to the fiber(E_2) for a unidirectional layer.

$$E_2 = \frac{E_f E_m}{\emptyset_f E_m + (1 - \emptyset_f) E_f}$$

g) The stiffness in the fiber direction for a unidirectional layer is given by:

$$E_1 = \emptyset_f E_f + (1 - \emptyset_f) E_m$$

Explain how the strength of layer in the fiber direction can be simplified into:

$$\sigma_1^{break} = \emptyset_f \sigma_f^{break}$$

h) What will happen with a flat unsymmetrical laminate plate if you change the temperature?

i) Show that the stiffness transverse to the fibers in a unidirectional lamina can be written as:

$$E_y = Q_{22} - \frac{Q_{12}^2}{Q_{11}}$$

j) Draw up a symmetric laminate and explain why [B]=0 for a symmetric laminate.

Task 2: Production methods

a) Mention some of the most used production methods for manufacturing composite parts and mention one main advantage for each method.
b) Which method do you choose if you want to build a complex one-off part with no surface requirements and low budget?
c) Which method do you choose if you want to produce 3km composite L-beam?
d) Which method do you choose if you need a high quality laminate, with no air inclusions and with surface requirements on both sides of the composite part?

Task3: The water reservoir

For a new water reservoir our client wants to use composite material due to maintenance free surface. The tank is to be made using glassfiber CSM 450g/m2 and a vinylester resin. The weight fraction of fiber is 0.45.

The open tank has a diameter of 10m, and the water height is 8m. The client wants a safety factor of 10 for the design. The pressure given by the water height is:

$$p = \rho g h$$

The strain at break is 1.8% for the composite.

E_{fiber}=72 GPa, E_{matrix}=3 GPa

Density: $\rho_f = \frac{2500kg}{m^3}, \rho_m = \frac{1200kg}{m^3}, \rho_{water} = \frac{1000kg}{m^3},\ g = 9.8\frac{m}{s^2}$

Use for the stiffness of a CSM layer:

$$E_{csm} = \emptyset_f \frac{3}{8} E_f + (1 - \emptyset_f) E_m$$

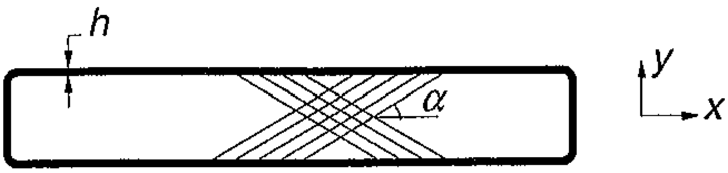
Stress in the lower part of the tank wall due to water pressure can be given as:

$$\sigma_{csm} = \frac{P\ r}{t}$$

Find the number of layers you need to build the tank with safety factor of 10.

Task 4: The pressure vessel

Our pressure vessel has a radius of 600mm and the laminate lay-up is $[(55,-55)_5]_s$. Every layer has a thickness of 0.5mm.



The vessel has no internal liner so resin cracks can not be allowed. For the unidirectional lamina we have the following properties: E_1=40 GPa: E_2=9.3 GPa: G_{12}=2.8 GPa: v_{12}=0.3

The failure stress for the lamina is given by:

$\sigma_1^T = 1100Mpa, \sigma_2^T = 20Mpa$

a) Find the stiffness matrix Q^0 for the unidirectional lamina

b) Calculate the Q_{22} element in the stiffnes matrix for 55° layer given below

$$Q^{55} = \begin{bmatrix} 12739 & 10448 & 4546 \\ 10448 & 23301 & 9963 \\ 4546 & 9963 & 10242 \end{bmatrix} [MPa], \quad Q^{-55} = \begin{bmatrix} 12739 & 10448 & -4546 \\ 10448 & 23301 & -9963 \\ -4546 & -9963 & 10242 \end{bmatrix} [MPa]$$

c) Calculate A_{11} element in the laminate stiffness matrix given below.

$$A = \begin{bmatrix} 127.39 & 104.5 & 0 \\ 104.5 & 233.0 & 0 \\ 0 & 0 & 102.4 \end{bmatrix} [10^3 N/mm]$$

Global stresses x,y for a pressure vessel is given by:

$$\sigma_x = \frac{P\,r}{2h} \quad \text{and} \quad \sigma_y = \frac{P\,r}{h}$$

and laminate forces is given by $N_x = h\sigma_x \quad og \quad N_y = h\sigma_y$

d) Find the global strains as a function of pressure for the pressure vessel.

$$\varepsilon_x = A \times p \quad \varepsilon_y = B \times p \qquad \gamma_{xy} = 0$$

e) At what pressure will the vessel start to leak(exceed the local systems stress limit)?

Rotation of stiffnesses:

$$Q_{11} = Q_{l11}\cos^4\theta + 2(Q_{l12} + 2Q_{l66})\cos^2\theta\sin^2\theta + Q_{l22}\sin^4\theta$$

$$Q_{12} = (Q_{l11} + Q_{l22} - 4Q_{l66})\cos^2\theta\sin^2\theta + Q_{l12}(\sin^4\theta + \cos^4\theta)$$

$$Q_{22} = Q_{l11}\sin^4\theta + 2(Q_{l12} + 2Q_{l66})\cos^2\theta\sin^2\theta + Q_{l22}\cos^4\theta$$

$$Q_{16} = (Q_{l11} - Q_{l12} - 2Q_{l66})\sin\theta\cos^3\theta + (Q_{l12} - Q_{l22} + 2Q_{l66})\sin^3\theta\cos\theta$$

$$Q_{26} = (Q_{l11} - Q_{l12} - 2Q_{l66})\sin^3\theta\cos\theta + (Q_{l12} - Q_{l22} + 2Q_{l66})\sin\theta\cos^3\theta$$

$$Q_{66} = (Q_{l11} + Q_{l22} - 2Q_{l12} - 2Q_{l66})\sin^2\theta\cos^2\theta + Q_{l66}(\sin^4\theta + \cos^4\theta)$$

<u>Transformation of strains from global to local :</u>

$$\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{pmatrix} = \begin{bmatrix} c^2 & s^2 & sc \\ s^2 & c^2 & -sc \\ -2sc & 2sc & c^2 - s^2 \end{bmatrix} \begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{pmatrix}$$

<u>Stresses in local system:</u>

$$\begin{pmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{pmatrix} = \underbrace{\frac{1}{1-\nu_{12}\nu_{21}} \begin{bmatrix} E_1 & \nu_{21}E_1 & 0 \\ \nu_{12}E_2 & E_2 & 0 \\ 0 & 0 & G_{12}(1-\nu_{12}\nu_{21}) \end{bmatrix}}_{[Q]^l} \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{pmatrix}$$