Unit 19 · Cement

ANSWER KEY · FOR TEACHERS

Full marks 36

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

K · 3

1. calcareous material → **f.** a raw material rich in lime, such as limestone
2. argillaceous material → **e.** a raw material rich in clay, supplying silica and alumina
3. clinker → **b.** the small, hard, dark gray lumps that come out of the kiln
4. pozzolana → **c.** a material rich in reactive silica, such as fly ash
5. non-hydraulic cement → **a.** a cement that hardens only in dry air, by taking up carbon dioxide
6. efflorescence → **g.** white salty patches on walls, from too much alkali oxide

Each carries 0.5 mark.

2 Label the diagram

K · 2

1. Mixing with water slurry, 30–40% water
2. Homogenization stirred slurry tank
3. Clinker formation rotary kiln, about 1450 °C
4. Grinding with 3–5% gypsum

Each carries 0.5 mark.

3 Multiple choice

i. **c.** 60–67% — K · 1

Lime from the limestone is 60–67% of cement; silica, alumina and iron oxide together about 20–30%; gypsum 3–5%.

ii. **a.** tricalcium silicate, C_3S — U · 1

C_3S reacts with water in hours and days; C_2S gives the later strength, over weeks and months. C_3A reacts fastest of all but adds little strength.

iii. **b.** move in opposite directions — K · 1

The meal slides down towards the flame while the gas moves up and out (countercurrent), so the meal meets hotter and hotter gas and the gas leaves having given up much of its heat.

iv. **c.** reacts with water after the concrete has set, swells and cracks it — U · 1

A little MgO adds hardness, but it reacts slowly with water after setting and swells.

v. **b.** its compressive strength in N/mm^2 at 28 days — K · 1

OPC is sold in grades 33, 43 and 53: the strength of standard cubes of its mortar at 28 days, in N/mm^2.

4 Short answers

a. MARKING SCHEME — A · 2

✓ $CaCO_3 \xrightarrow{800\text{–}900\ ^\circ C} CaO + CO_2$

✓ $3\,CaO + SiO_2 \rightarrow Ca_3SiO_5$

b. MARKING SCHEME — U · 2

✓ Cement is the gray powder, the binder; mortar is cement + sand + water, for joining bricks and plastering.

✓ Concrete is cement + sand + gravel (crushed stone) + water, for floors, columns, roads and dams.

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c. MARKING SCHEME U · 2

- ✓ Gypsum reacts with tricalcium aluminate as soon as water is added and coats it, so the paste stays workable for an hour or two: it regulates the setting time.
- ✓ Without it the C_3A would react with water at once and the paste would stiffen in minutes (flash setting).

d. MARKING SCHEME U · 2

- ✓ Its reactive silica reacts with the calcium hydroxide set free when cement hydrates, forming more calcium silicate hydrate (C–S–H).
- ✓ So the weak, soluble $Ca(OH)_2$ that water and chemicals attack becomes strong binder, and the concrete is denser and less permeable.

e. MARKING SCHEME U · 3

- ✓ The balanced equation.
- ✓ C_3S hydrates quickly: early strength.
- ✓ C_2S hydrates over weeks and months: the later strength.

5 Long answer

ANSWER A · 4

OPC is clinker ground with gypsum; PPC is OPC clinker and gypsum ground with a pozzolana, usually fly ash (15–35% of the cement).

OPC sets faster, gives high early strength and more heat of hydration; PPC gives less heat and lower early strength, but equal or higher strength in the long run, and resists sulphates, chlorides and water better.

PPC is greener: less clinker is made, so less fuel is burned and less CO_2 given off, and it uses an industrial waste; it is also often cheaper.

For a dam, PPC: in a large mass of concrete the heat can't escape, and OPC's heat would crack it as the outside cools; PPC also resists water. For loaded columns, OPC, for its high early strength.

MARKING SCHEME

- ✓ What is in each: clinker + gypsum; clinker + gypsum + pozzolana.
- ✓ Heat and strength: OPC more heat and early strength; PPC less heat, later strength, more durable.
- ✓ Environment: PPC uses less clinker, so less fuel and CO_2, and recycles fly ash.
- ✓ PPC for the dam (less heat, so no cracking); OPC for the columns (early strength).

6 Numerical problems

a. ANSWER A · 4

i. $CaCO_3 \rightarrow CaO + CO_2$

ii. 100 g of $CaCO_3$ gives 56 g of CaO, so $CaCO_3 = 650\ \text{kg} \times 100 \div 56 =$ **1161 kg** (about 1.16 t).

iii. $CO_2 = 1161\ \text{kg} \times 44 \div 100 =$ **511 kg**; $511\,000\ \text{g} \div 44\ \text{g/mol} = 11\,610\ \text{mol} \times 22.4\ \text{L/mol} = 2.60 \times 10^5$ L = **260 m³**.

iv. Gypsum $= 0.04 \times 50\ \text{kg} =$ **2.0 kg**.

MARKING SCHEME

- ✓ The balanced equation.
- ✓ 1161 kg of $CaCO_3$.
- ✓ 511 kg of CO_2, 260 m^3 at STP.
- ✓ 2.0 kg of gypsum.

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b. **ANSWER** A · 4

i. The dry solids are 65% of the slurry, so slurry = 1000 kg ÷ 0.65 = 1538 kg, and water = 1538 − 1000 = **538 kg**.
ii. Heat = 538 kg × 2.3 MJ/kg = **1240 MJ** (about 1.24 GJ).
iii. Coal = 1240 MJ ÷ 24 MJ/kg = **52 kg** for each tonne of raw materials.
iv. In the dry process the raw materials are ground dry, as raw meal, and dried by the kiln's own exhaust gas, so there is no slurry water to boil off in the kiln.

MARKING SCHEME

✓ 538 kg of water.
✓ 1240 MJ.
✓ 52 kg of coal.
✓ Dry raw meal, dried by kiln gas: no water to evaporate.

7 Think

ANSWER HA · 3

The CO_2 is a product of the chemistry: $CaCO_3 \rightarrow CaO + CO_2$. Every 56 kg of lime in the clinker sets free 44 kg of CO_2, however the kiln is heated, so changing the fuel changes only the other half. PPC replaces 15–35% of the cement with a pozzolana such as fly ash, so less clinker has to be made for each bag, less limestone is calcined, and less CO_2 is given off.

MARKING SCHEME

✓ The CO_2 comes from calcination itself, $CaCO_3 \rightarrow CaO + CO_2$.
✓ It is set free whatever heats the kiln (44 kg for every 56 kg of CaO).
✓ PPC needs less clinker, so less limestone is broken down.

8 Activity: Lime mortar and cement mortar

(not marked)

WHAT STUDENTS SHOULD FIND

The cement mortar sets hard in a day and goes on hardening, in air and under water alike: it hardens by reacting with water, so it is hydraulic. The lime mortar stays soft for a long time, hardens only slowly in air as it takes up carbon dioxide ($Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$), and under water stays soft and crumbles: it is non-hydraulic.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	8	11	14	3	**36**

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