HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 35

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

1 From limestone to clinker: where the mass goes

a. ANSWER A · 4

Tests: the mass lost on calcination, $CaCO_3 \rightarrow CaO + CO_2$, and why the raw mix is richer in limestone than the clinker is in lime.

$M(CaCO_3) = 100.09$, $M(CaO) = 56.08$, $M(CO_2) = 44.01$ g/mol.

i. 0.65 t of CaO needs $0.65 \times 100.09/56.08 =$ **1.16 t of limestone**.

ii. $CO_2 = 0.65 \times 44.01/56.08 =$ **0.51 t** $(1.16 - 0.65)$.

iii. Raw meal $= 1.16 + 0.35 = 1.51$ t, of which limestone is $1.16/1.51 =$ **77%**, about three-quarters. Both are right because limestone loses 44% of its mass (44.01/100.09) as CO_2 in the kiln, while the clay (here) loses nothing: the limestone's share shrinks from 77% of what goes in to 65% of what comes out. The tempting answer, "limestone is 65% of the mix because CaO is 65% of the clinker", forgets the CO_2.

MARKING SCHEME

✓ 1.16 t of limestone.

✓ 0.51 t of CO_2.

✓ Limestone is 77% of the raw meal.

✓ It loses 44% of its mass as CO_2, so its share falls from 77% of the feed to 65% of the clinker.

b. ANSWER HA · 2

Tests: a mass balance deciding where a plant stands.

To make a tonne of clinker the kiln must be fed about **1.5 t of raw meal**, of which **0.5 t leaves as CO_2** from the chimney: carrying limestone far to a kiln would mean paying to haul a third of it only to let it go as gas. So the kiln sits at the quarry, and what travels is the **clinker** (1 t, with 3–5% gypsum to add), the lighter, finished-burned product; a grinding plant needs only clinker, gypsum and power, so it can sit near the market or the border.

MARKING SCHEME

✓ About 1.5 t of raw meal per tonne of clinker, a third of it lost as CO_2: haul it as little as possible, so the kiln is at the quarry.

✓ Only clinker (plus gypsum) travels to a grinding plant, which can be near the buyers.

2 Fuel or rock: Nepal's cement CO_2

a. ANSWER A · 3

Tests: how the share of clinker, not the fuel, sets the CO_2 from the limestone.

i. OPC: $0.95 \times 0.51 = 0.485$ t CO_2 per tonne of cement; $\times$ 8 Mt = **3.9 million tonnes**. PPC: $0.65 \times 0.51 = 0.332$ t per tonne; $\times$ 8 Mt = **2.7 million tonnes**.

ii. 0.153 t per tonne of cement, $0.153/0.485 =$ **about a third (32%) less**, **1.2 million tonnes** in all.

iii. **No.** The fuel is burned in the kiln, to heat the raw meal to 1450 °C and make clinker; the mills run on electricity. PPC needs about a third less clinker per tonne of cement (65% against 95%), so the kiln burns about a third less fuel for each tonne of cement too: the fuel's CO_2 falls by about the same fraction as the limestone's (the unit: PPC uses less energy because less clinker is made). What doesn't shrink is the electricity the mills use for grinding.

MARKING SCHEME

✓ OPC about 3.9 and PPC about 2.7 million tonnes.

✓ A cut of about a third (0.15 t per tonne of cement), 1.2 million tonnes in all.

✓ No: the fuel makes clinker in the kiln, so with a third less clinker the fuel's CO_2 falls by about a third too.

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b. ANSWER HA · 4

Tests: the two sources of cement's CO_2, only one of them fuel; the trade-off in replacing clinker.

i. **Only half true.** Electric heating could remove the fuel's CO_2, roughly half of cement's CO_2 (the unit). But the other half is chemistry: $CaCO_3 \rightarrow CaO + CO_2$ gives off 0.51 t of CO_2 per tonne of clinker whatever heats the kiln, since there is no CaO without it. Only less clinker per tonne of cement (PPC, slag cements) cuts that part.

ii. Any two: PPC gains strength **slowly** and sets more slowly, so it needs longer curing and doesn't suit work needing early strength (precast, prestressed and urgent work); its quality depends on the **fly ash**, which comes from coal power stations and is mostly imported (Nepal's electricity is hydropower), so more of it means more dependence and transport; the standards limit a pozzolana to **15–35%** of PPC.

MARKING SCHEME

- ✓ Electricity removes only the fuel's share, about half.
- ✓ The CO_2 from calcining limestone stays (0.51 t per tonne of clinker); only less clinker cuts it.
- ✓ One reason: slow early strength and setting, longer curing, unsuitable where early strength is needed.
- ✓ Another: depends on fly ash quality and supply (mostly imported), or the standards' 15–35% limit.

3 The price of water in the wet process

a. ANSWER A · 3

Tests: what "more fuel" in the wet process amounts to, from the unit's own numbers.

i. The slurry is 65% solids, so water = $1.5 \times 35/65$ = **0.81 t per tonne of clinker**; heat = 808 kg × 2.3 MJ/kg = **1.9 GJ** (1,860 MJ). (Tempting slip: 35% of 1.5 t, 0.53 t: the 35% is of the slurry, water included.)

ii. 1,860 MJ ÷ 25 MJ/kg = 74 kg of coal per tonne of clinker; × 800 t = **about 59 tonnes of coal a day**. (The 25 MJ/kg is a typical value for coal, given in the question.)

MARKING SCHEME

- ✓ Water 0.81 t per tonne of clinker (35% of the slurry, not of the solids).
- ✓ Heat about 1.9 GJ per tonne of clinker.
- ✓ About 59 t of extra coal a day.

b. ANSWER HA · 2

Tests: the wet and dry processes as a trade-off, and why each step of the dry line is where it is.

The slurry, stirred in tanks, **blends evenly** with little effort (and grinds wet without dust): the composition of the feed, which decides the clinker, is easy to keep right. A dry plant gets an even feed by **blending in silos with compressed air and analyzing samples continuously**, correcting the oxides. And instead of using the kiln's hot gas to boil off water, it sends that gas **up the preheater**, against the falling raw meal (countercurrent), so the meal is hot, and mostly calcined in the precalciner, before it enters the kiln; the air that cools the clinker goes back to burn the fuel.

MARKING SCHEME

- ✓ Wet: even blending of the feed (easy to control its composition).
- ✓ Dry: air blending and continuous analysis; the kiln gas preheats the meal in the cyclones (countercurrent) instead of boiling water.

4 Gypsum belongs in the mill

ANSWER

Tests: why each ingredient enters where it does; flash setting as a reaction of C_3A, not a lack of water.

i. It would **flash set**. In the kiln at 1400–1500 °C the gypsum would lose its water and decompose, so no gypsum would reach the finished cement. Nothing would then hold back the **tricalcium aluminate**: it would react with water almost at once, and the cement would stiffen within minutes, too fast to mix, carry and place. That is why gypsum goes in the mill, after the kiln.

ii. **The plant with 12% C_3A.** Gypsum's job is to coat and hold back the C_3A; twice as much C_3A needs more of it, so that clinker takes gypsum near 5%, the other nearer 3%.

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iii. The **tricalcium aluminate (C_3A)** is reacting at once: the batch has **too little gypsum** (or none; or it was spoiled before grinding) to coat the C_3A. The stiffening is a **chemical reaction**: new hydrated compounds have already formed and locked the paste; it hasn't dried out, so water doesn't undo it. HA · 5

MARKING SCHEME

- ✓ Gypsum would decompose in the kiln, so none would be in the cement.
- ✓ C_3A then reacts at once with water: flash setting.
- ✓ The 12% C_3A clinker needs more gypsum, since gypsum holds back C_3A.
- ✓ The C_3A is reacting; the batch lacks gypsum.
- ✓ The stiffening is a reaction already done, not drying, so more water can't reverse it.

5 Concrete doesn't dry hard

a. **ANSWER** A · 4

Tests: hydration as a reaction that uses water and frees $Ca(OH)_2$, worked from the unit's equations. $M(Ca_3SiO_5) = 228.33$, $M(Ca_2SiO_4) = 172.25$, $M(H_2O) = 18.02$, $M(Ca(OH)_2) = 74.10$ g/mol. C_3S: 27.5 kg; C_2S: 10.0 kg.

i. C_3S: $27.5 \times (6 \times 18.02)/(2 \times 228.33) = 6.5$ kg; C_2S: $10.0 \times (4 \times 18.02)/(2 \times 172.25) = 2.1$ kg; in all **about 8.6 kg of water per bag**.

ii. C_3S: $27.5 \times (3 \times 74.10)/(2 \times 228.33) = 13.4$ kg; C_2S: $10.0 \times 74.10/(2 \times 172.25) = 2.2$ kg; in all **about 15.5 kg of $Ca(OH)_2$**. Per kilogram, **C_3S releases more**: 0.49 kg against 0.22 kg for C_2S.

MARKING SCHEME

- ✓ Water for C_3S 6.5 kg, for C_2S 2.1 kg.
- ✓ About 8.6 kg in all.
- ✓ About 15.5 kg of $Ca(OH)_2$ in all.
- ✓ C_3S releases more per kilogram (0.49 against 0.22 kg).

b. **ANSWER** HA · 3

Tests: hardening as hydration (curing), and why the pozzolana's reaction comes later.

i. **Wrong.** Concrete hardens because the silicates **react** with water: a bag binds about 8.6 kg of water into C–S–H and $Ca(OH)_2$. If the slab dries out, the water is gone before the reactions finish, and the slow one, C_2S's, which gives the strength of the later weeks and months, stops: the slab ends up weaker. Keeping it wet (curing) lets the reactions go on.

ii. **PPC.** Its pozzolana makes extra C–S–H by reacting with the **$Ca(OH)_2$ the clinker releases**, so that reaction can only follow the clinker's own hydration, and it is slow; it needs water for longer.

MARKING SCHEME

- ✓ Hardening is hydration, a reaction that uses water (about 8.6 kg a bag).
- ✓ Drying stops it, especially the slow C_2S reaction, so the slab is weaker: curing keeps it going.
- ✓ PPC: the pozzolana reacts later, with the $Ca(OH)_2$ the clinker releases, so it needs longer curing.

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6 Two bags on the site

ANSWER HA · 5

Tests: reading OPC and PPC from data where early strength and heat pull one way and long-term strength and durability the other; what a grade number means.

i. **X is OPC, Y is PPC**: X is stronger early (23 against 16 N/mm^2 at 3 days) and warms its block more (45 against 32 °C, more heat of hydration); Y overtakes it later (55 against 52 at 90 days).

ii. A grade is the strength at 28 days: X reaches 47 N/mm^2, so it **meets 43 but not 53**. PPC **isn't sold in grades** (it must only meet one minimum strength), so "grade 42" means nothing.

iii. **Foundation: Y.** In a thick mass the heat can't escape; OPC's larger temperature rise makes the inside expand while the outside cools, and the mass cracks; Y gives less heat, is denser and more durable, and there is time to wait for its strength. **Precast beams: X.** The molds are reused at 3 days, so early strength decides: 23 against 16 N/mm^2.

iv. Y is weaker only **early**. By 90 days it is the stronger (55 against 52), and a foundation carries its full load months after it is cast, so the early figure doesn't decide; its lower heat does. (The strengths and temperatures are made up, of the size such cements give.)

MARKING SCHEME

- ✓ X OPC, Y PPC: higher early strength and more heat in X; Y stronger by 90 days.
- ✓ X meets OPC 43 (47 at 28 days), not 53; PPC isn't graded.
- ✓ Foundation: Y, less heat of hydration, so no cracking of the mass.
- ✓ Precast beams: X, early strength at 3 days.
- ✓ Y is weaker only early; by 90 days it is stronger, which is what the foundation needs.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	0	14	21	**35**

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