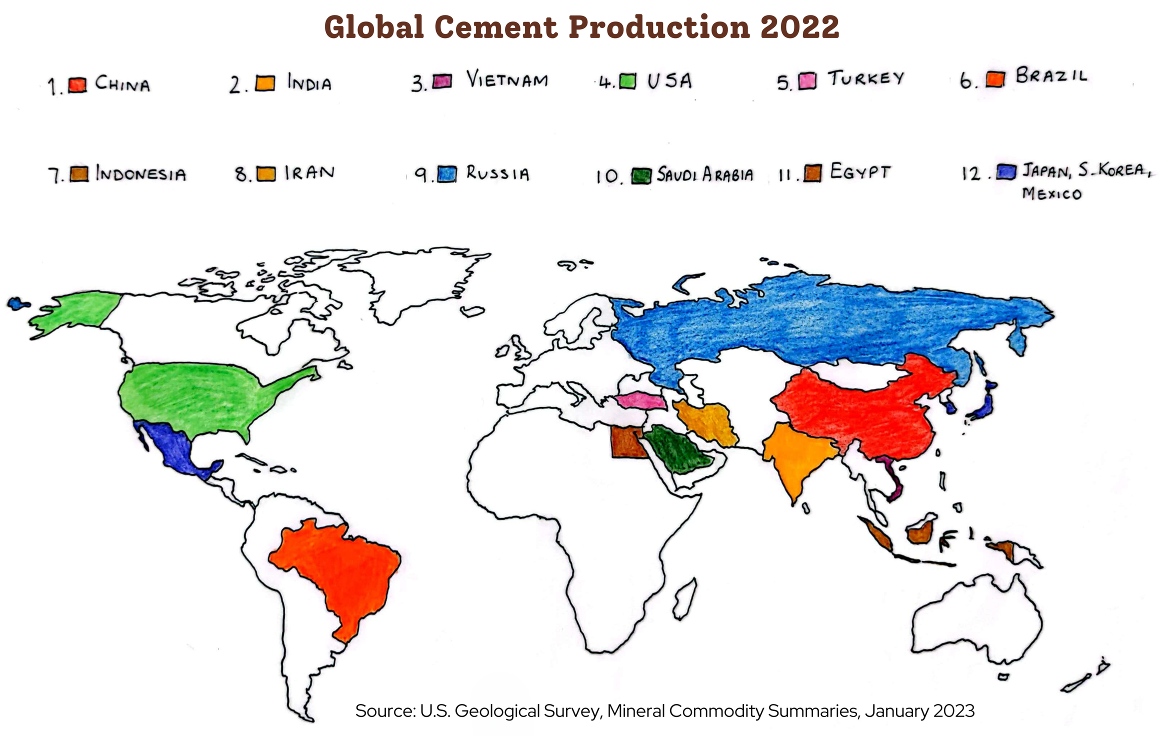
Replacement with Eggshell Waste and Glycerine

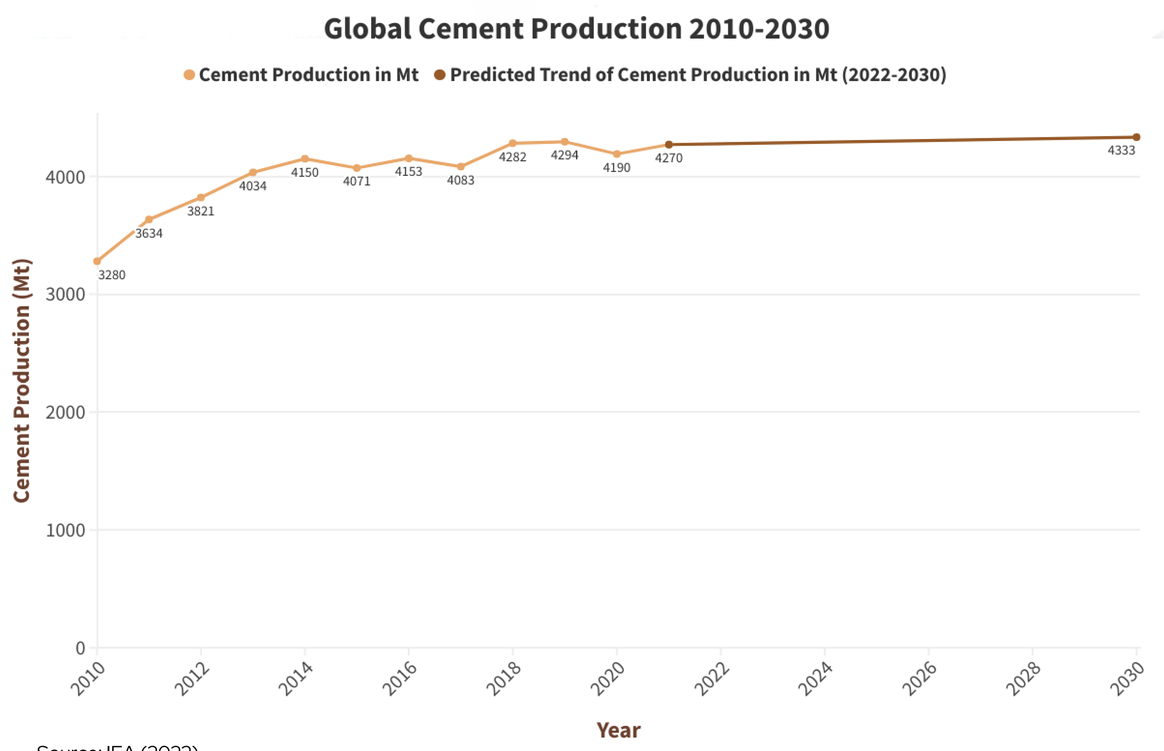
Title
An evaluation of the mechanical and structural performance of concrete using eggshell waste and glycerine

Aim
Investigate the mechanical and structural performance properties of concrete containing eggshell powder (ESP) and glycerine.

Objectives
1. Create and prepare ESP from waste eggshells only, excluding calcination from the process
2. Create 11 samples of concrete: 2 control samples and 9 experimental samples
3. Identify and analyse the workability and compressive strength properties of all samples
4. Investigate the material savings of all samples
5. Explore areas of application and challenges that this material faces in developing as a building material

Motivation





Source: IEA (2022)

The manufacturing of cement generates extreme amounts of heat using **fossil fuels** that emit detrimental amounts of **carbon dioxide** into the atmosphere, damaging our planet.

11%

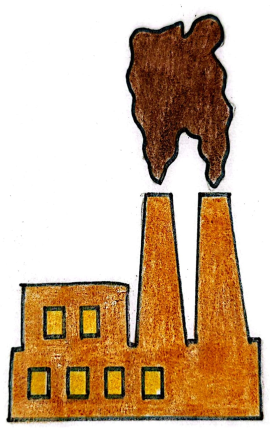
Greenhouse gas (GHG) emissions in Ireland have risen by **11%** between 1990–2021

The construction sector is **not on track** !

to achieve decarbonization by **2050**.

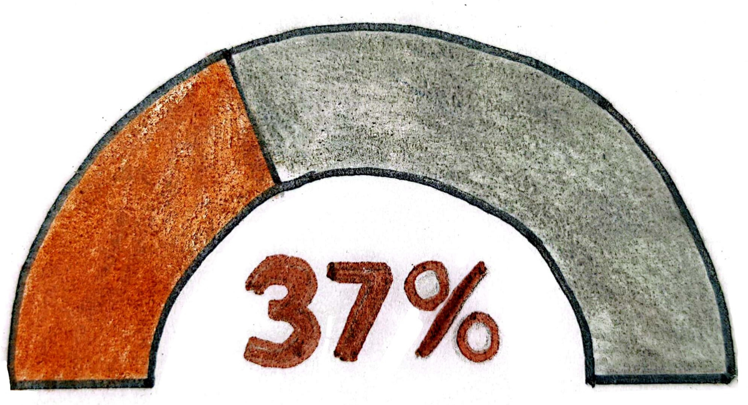
3% annual reductions of **carbon dioxide emissions** are required **until 2030** to align with the Net Zero Emissions by 2050 Scenario.

Scarcity of fresh water in countries worldwide inspires the need for development of **sustainable water-reducing admixtures** for concrete manufacturing



8% of the construction industry's total carbon emissions comes from cement manufacturing.

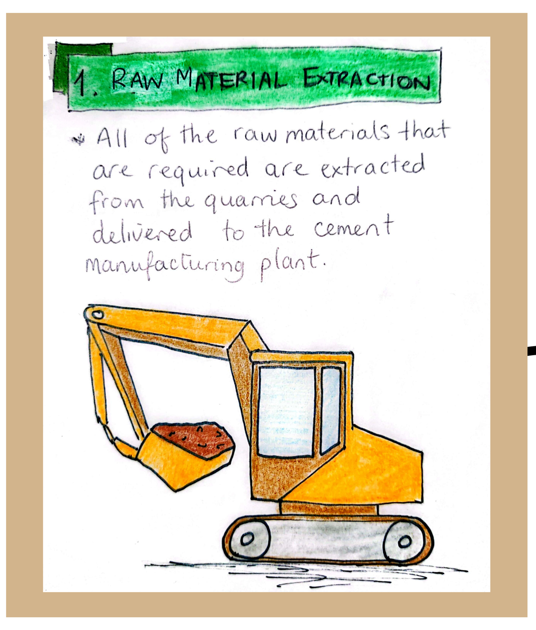
Is there a way of reducing the cement content of concrete with a material that does not cause extreme carbon dioxide pollution to create?

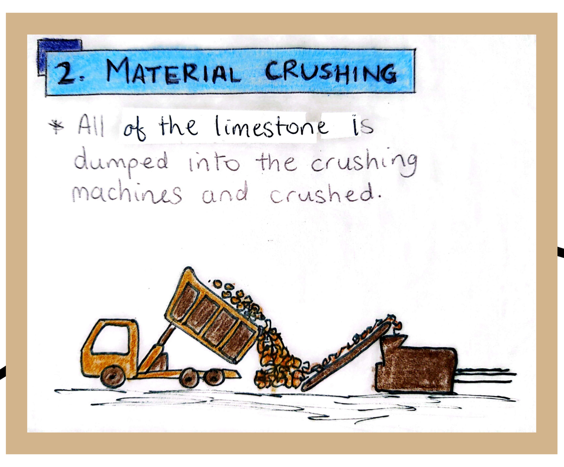


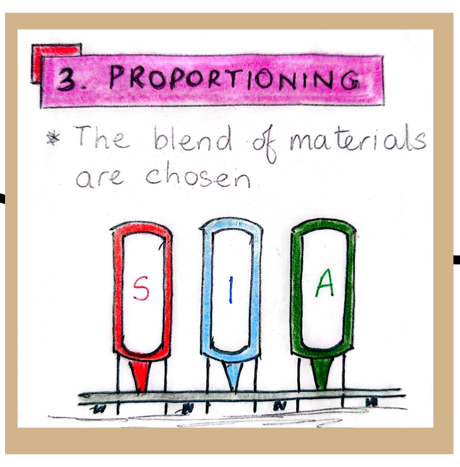
The construction industry accounts for approximately **37%** of global energy and process-related carbon emissions.

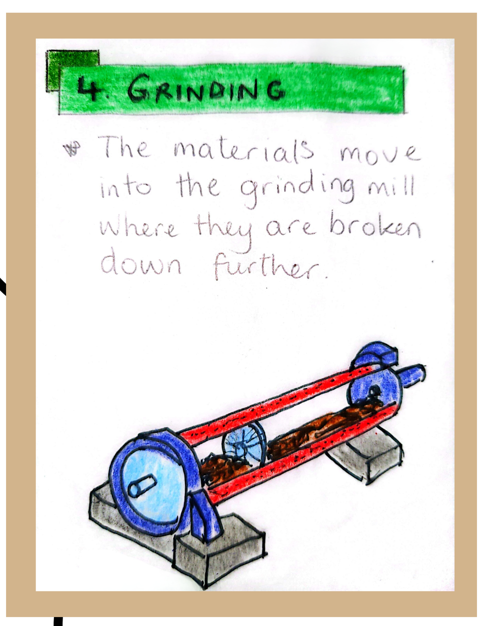
Current Cement Manufacturing Process

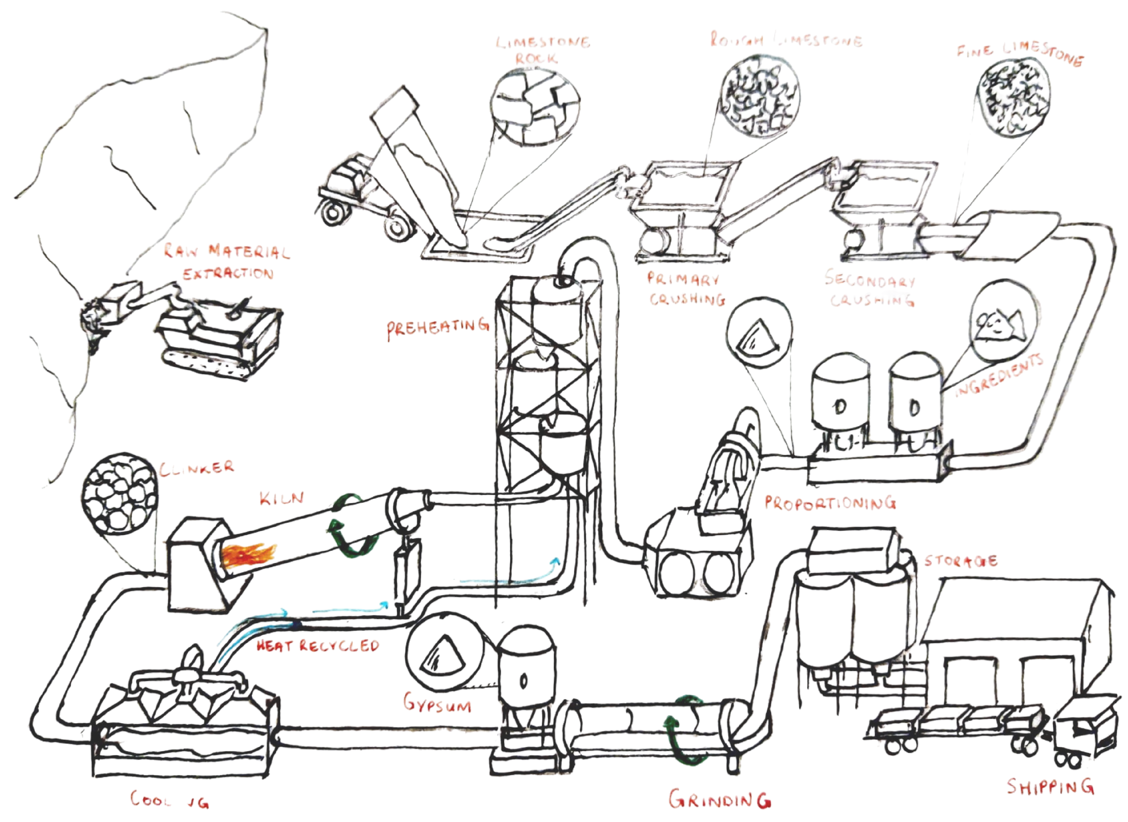
Calcium Carbonate + Heat = Lime + CARBON DIOXIDE

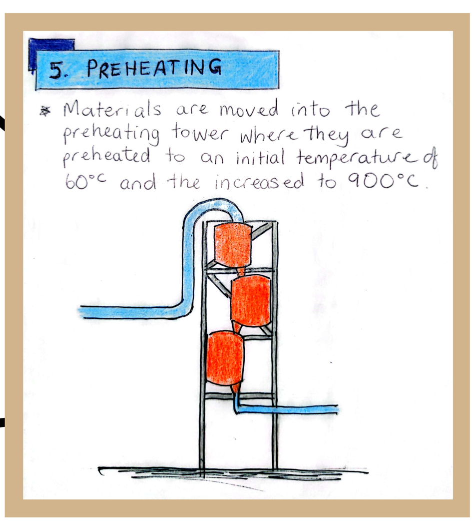


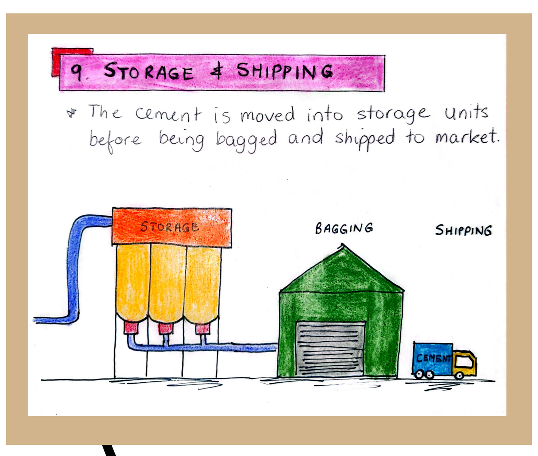


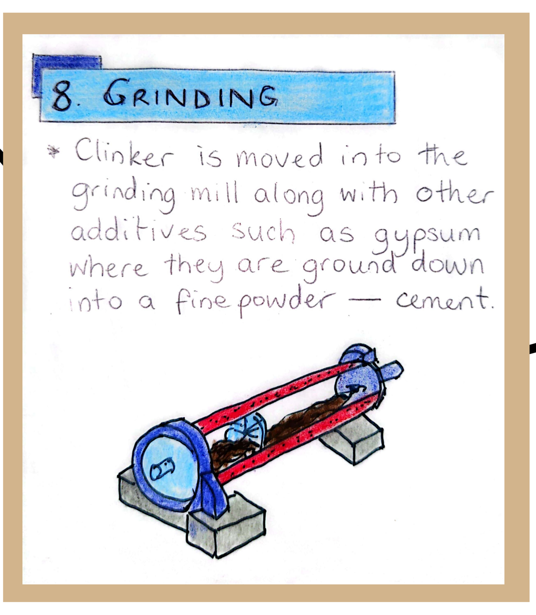


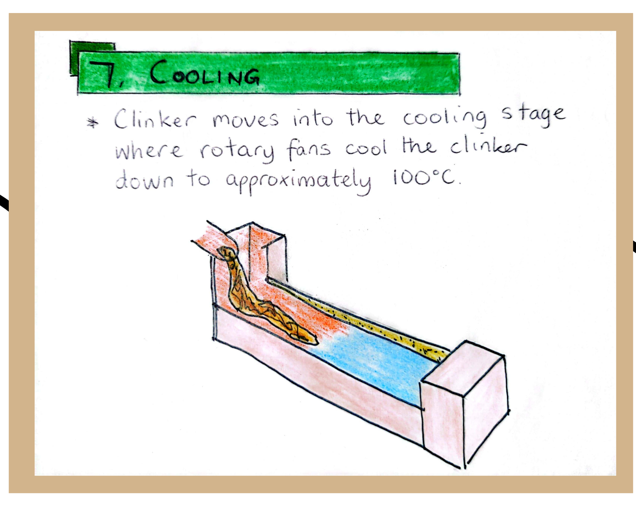


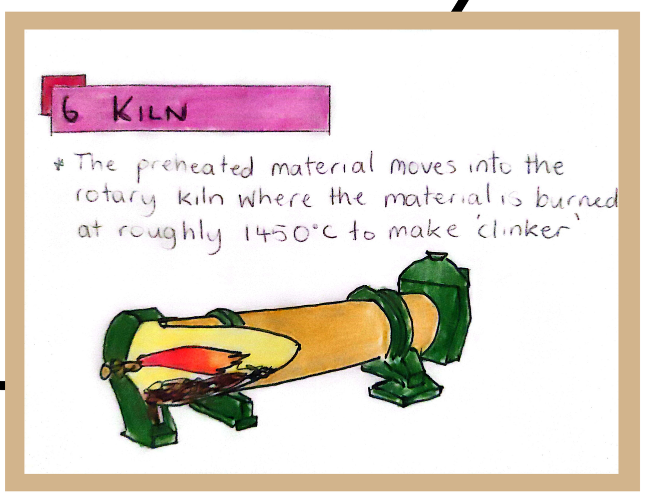












Why **Eggshells?**
- Considered a hazardous waste by the EU.
- Widely available from houses, bakeries and restaurants.
- Composed of approximately 94% calcium carbonate.

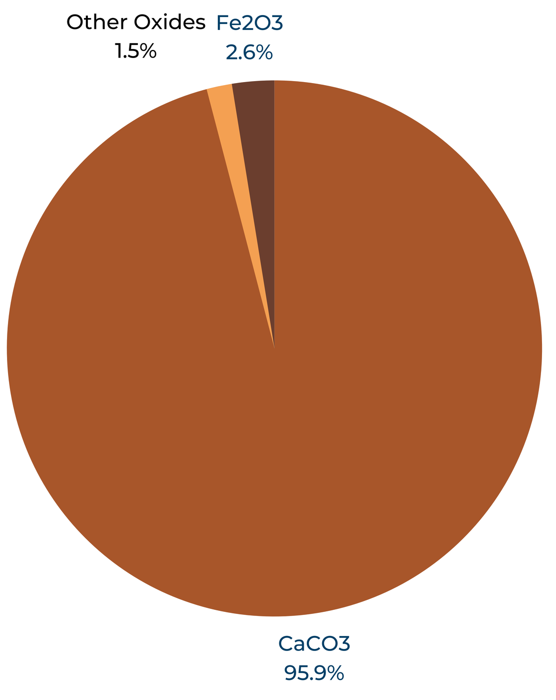
Why **Glycerine?**
- Derived from vegetables, plants, animals and petroleum.
- Is a by-product of the biodiesel industry.
- Promotes the use of biodiesel which is a sustainable alternative to traditional diesel.

Current use of materials:
- cosmetic industry
- paper manufacturing
- glass manufacturing
- soil amendment
- animal feed
- food and drink industry

Where can change be applied?
- Methods of raw material extraction;
- Energy sources used for extreme heating or;
- Choice of materials used.

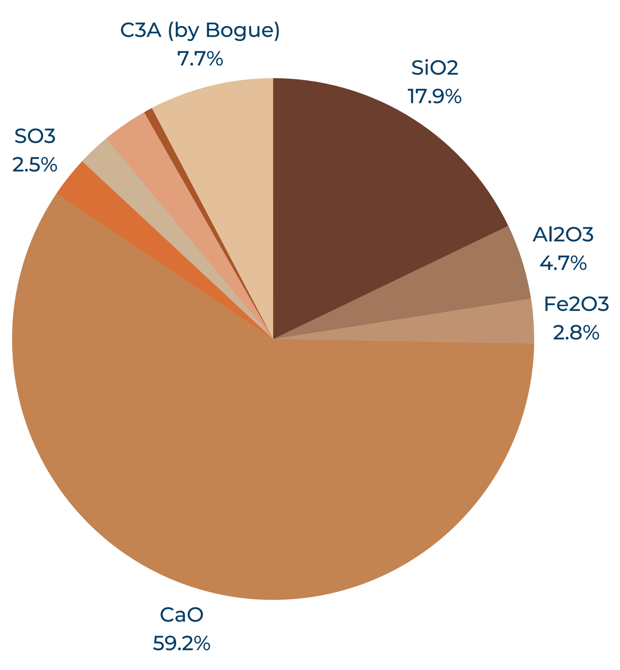
Chemical Composition Comparison

Eggshells



% IN EGGSHELLS	COMMON MATERIALS	% IN CEMENT
92-96%	Calcium Carbonate ($CaCO_3$)	—
Derived from $CaCO_3$ ↑	Calcium Oxide (CaO)	63·15%
	Silicon Dioxide (SiO_2)	19·06%
	Aluminium Oxide (Al_2O_3)	4·98%
Account for 1-5% along with other compounds	Ferric Oxide (Fe_2O_3)	2·95%
	Sodium Oxide (Na_2O)	< 0·6%
	Chlorine (Cl)	Weekly Reports

Cement



METHODOLOGY

Testing Timeline

- 1 — Creation, Workability, Casting
- 3 — Density (1), Curing
- 10 — Water Absorption (1), 7-Day Compressive Strength
- 17 — Water Absorption (2)
- 24 — Water Absorption (3)
- 31 — Water Absorption (4), Density (2), 28-Day Compressive Strength

Why?
What is the effect of using eggshell waste and glycerine in concrete on its compressive strength and workability without undergoing the calcination process?

What?
11 samples of concrete containing eggshell powder and glycerine

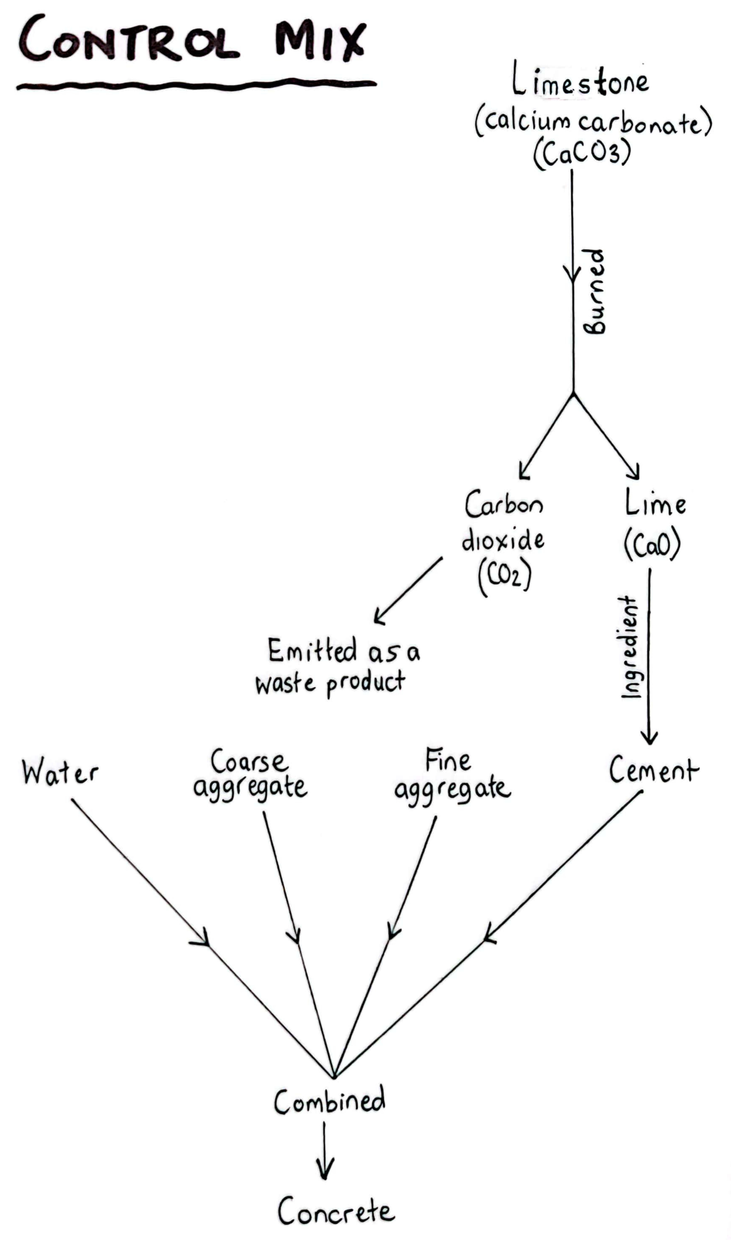
Where?
Concrete testing laboratory, TUD Bolton Street

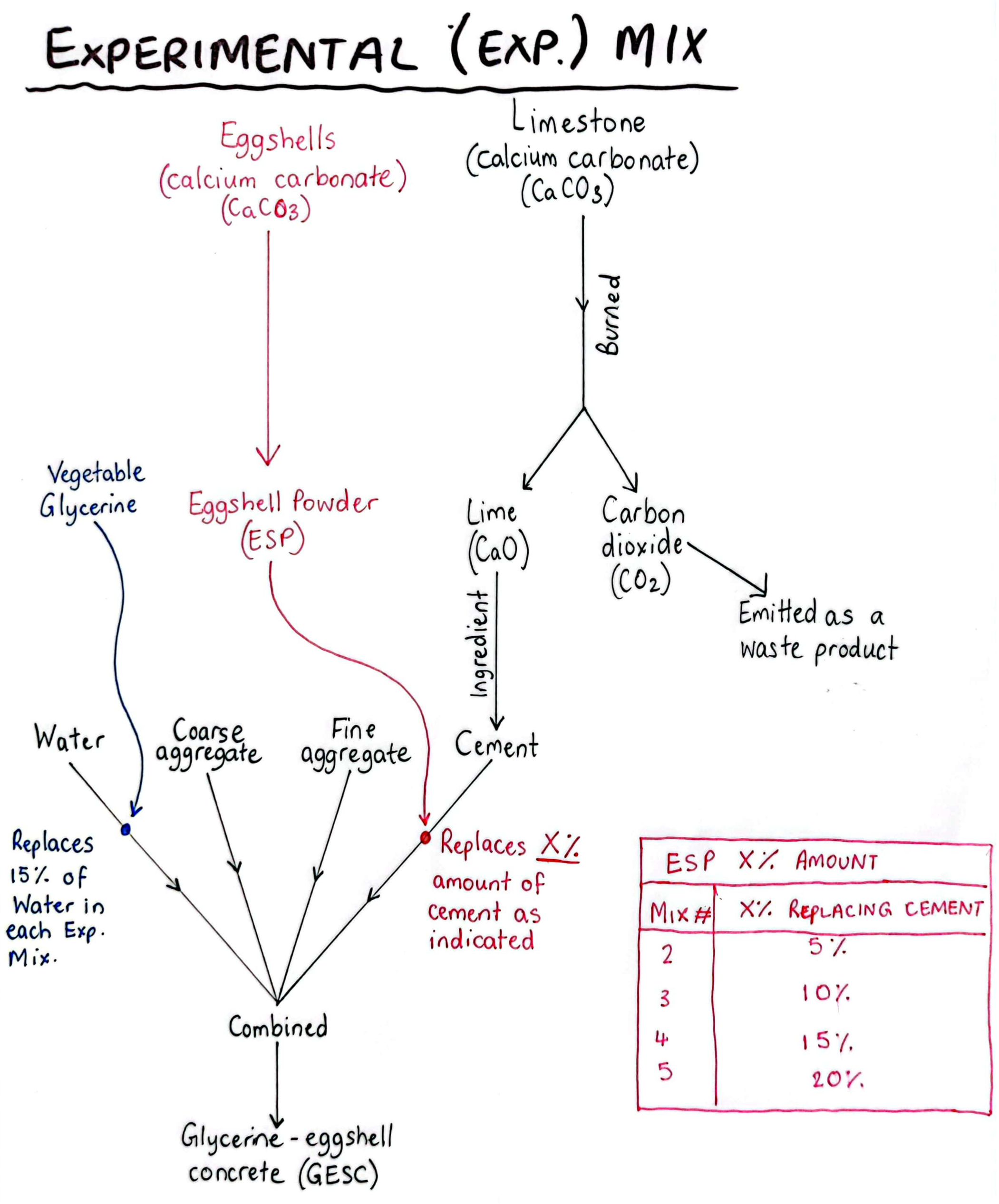
How?
- Creation of samples
- Workability testing
- Density calculations
- Water absorption measurements
- Compressive strength testing
- Material Savings analysis

Test Standards to be followed:
- I.S.EN12350-2-2019 Testing fresh concrete - Part 2: Slump test
- I.S.EN12390-1-2021 Testing hardened concrete - Part 1: Shape, dimensions and other requirements for specimens and moulds
- I.S.EN12390-2-2019 Testing hardened concrete - Part 2: Making and curing specimens for strength tests
- I.S.EN12390-3-2019 Testing hardened concrete - Part 3: Compressive strength of test specimens
- I.S.EN12390-4-2019 Testing hardened concrete - Part 4: Compressive strength - Specification of testing machines

Mix Design

How am I changing the creation process?





ESP X% AMOUNT	
MIX #	X% REPLACING CEMENT
2	5%
3	10%
4	15%
5	20%

Concrete mix design form — Job title: Unrestricted Design

Stage	Item		Reference or calculation	Values
1	1.1	Characteristic strength	Specified	35 N/mm² at 28 days; Proportion defective 5 %
	1.2	Standard deviation	Fig 3	N/mm² or no data 8 N/mm²
	1.3	Margin	C1 or Specified	(k = 1.64) 1.64 × 8 = 13.12 N/mm²; n/a N/mm²
	1.4	Target mean strength	C2	35 + 13.12 = 48.12 N/mm²
	1.5	Cement strength class	Specified	42.5/52.5
	1.6	Aggregate type: coarse; Aggregate type: fine		Crushed/uncrushed; Crushed/ uncrushed
	1.7	Free-water/cement ratio	Table 2, Fig 4	0.51 } Use the lower value: 0.50
	1.8	*Maximum free-water/ cement ratio*	*Specified*	0.50
2	2.1	Slump or Vebe time	Specified	Slump 60-180 mm or Vebe time n/a s
	2.2	Maximum aggregate size	Specified	20 mm
	2.3	Free-water content	Table 3	225 kg/m³
3	3.1	Cement content	C3	225 ÷ 0.50 = 450 kg/m³
	3.2	*Maximum cement content*	*Specified*	n/a kg/m³
	3.3	*Minimum cement content*	*Specified*	n/a kg/m³
				use 3.1 if ≤ 3.2; use 3.3 if > 3.1: 450 kg/m³
	3.4	Modified free-water/cement ratio		n/a
4	4.1	Relative density of aggregate (SSD)		2.7 known/assumed
	4.2	Concrete density	Fig 5	2380 kg/m³
	4.3	Total aggregate content	C4	2380 − 450 − 225 = 1705 kg/m³
5	5.1	Grading of fine aggregate	Percentage passing 600 μm sieve	70 %
	5.2	Proportion of fine aggregate	Fig 6	35 %
	5.3	Fine aggregate content	C5	1705 × 0.35 = 595 kg/m³
	5.4	Coarse aggregate content	C5	1705 − 595 = 1110 kg/m³

Quantities	Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg) 10 mm	20 mm	40 mm
per m³ (to nearest 5 kg)	450	225	595	370	740	n/a
per trial mix of 0.008 m³	3.6	1.8	4.76	2.96	5.92	n/a

Items in italics are optional limiting values that may be specified (see Section 7).
Concrete strength is expressed in the units N/mm². 1 N/mm² = 1 MN/m² = 1 MPa. (N = newton; Pa = pascal.)
The internationally known term 'relative density' used here is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.
SSD = based on the saturated surface-dry condition.

QUANTITIES OF MATERIALS – CUBES OF VOLUME 0.008m³* & 0.012m³**

MIX NUMBER	OPC (kg)	ESP (kg)	FA (kg)	CA (kg) 10mm	CA (kg) 20mm	WATER (L)	GLYCERINE (L)
Mix 1*	3.60	—	4.76	2.96	5.92	1.80	—
Mix 2**	5.13	0.27	7.14	4.44	8.88	2.30	0.41
Mix 3*	3.24	0.36	4.76	2.96	5.92	1.53	0.27
Mix 4*	3.06	0.54	4.76	2.96	5.92	1.53	0.27
Mix 5*	2.88	0.72	4.76	2.96	5.92	1.53	0.27
TOTAL	17.91	1.89	26.18	16.28	32.56	8.69	1.22
				48.84			

OPC : Ordinary Portland Cement
ESP : Eggshell Powder
FA : Fine Aggregate
CA : Coarse Aggregate

Sample size used : 150mm × 150mm × 150mm cube
Sample volume : 0.15m (150mm) × 0.15m (150mm) × 0.15m (150mm) = 0.0034 m³
0.0034 + extra mix as precaution measure = 0.004m³
* 0.008m³ ⟶ 0.004m³ × 2 samples = 0.008m³
** 0.012m³ ⟶ 0.004m³ × 3 samples = 0.012m³

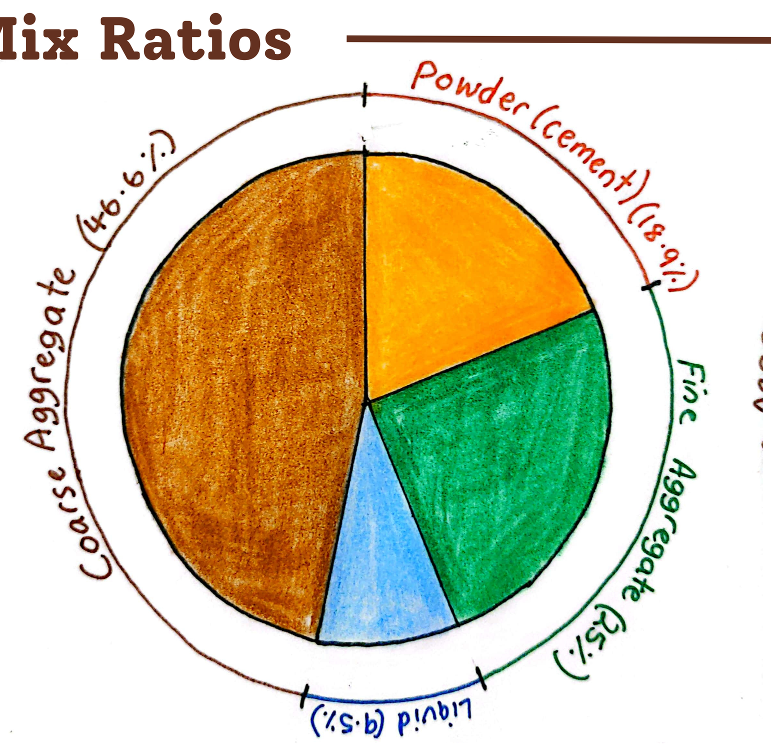
QUANTITIES OF MATERIALS – CUBES OF VOLUME 1m³

MIX NUMBER	OPC (kg)	ESP (kg)	FA (kg)	CA (kg) 10mm	CA (kg) 20mm	WATER (L)	GLYCERINE (L)
Mix 1	450	—	595	370	740	225	—
Mix 2	427.5	22.5	595	370	740	191.25	33.75
Mix 3	405	45	595	370	740	191.25	33.75
Mix 4	382.5	67.5	595	370	740	191.25	33.75
Mix 5	360	90	595	370	740	191.25	33.75
TOTAL	2025	225	2975	1850	3700	990	135
				5550			

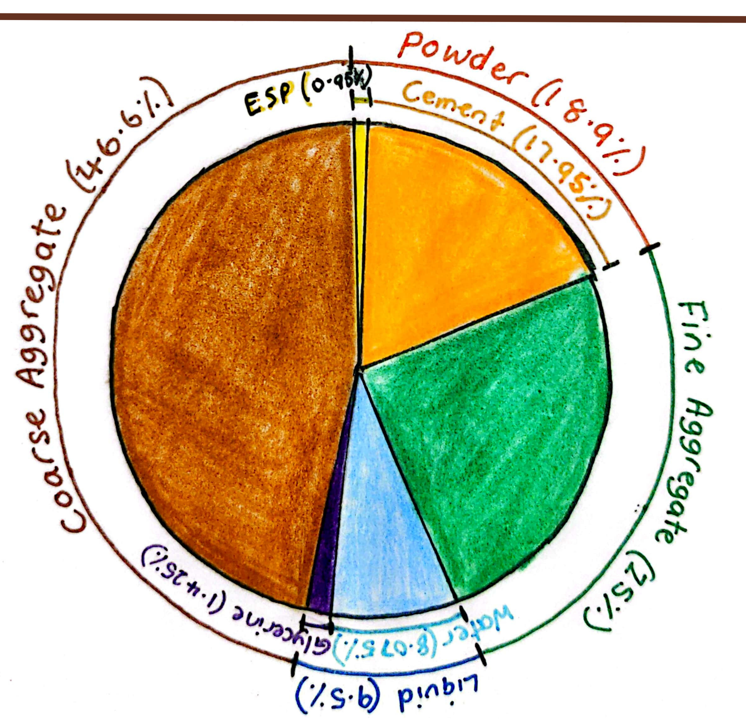
What percentage of material is being replaced?

MIX NUMBER	ESP CONTENT	GLYCERINE CONTENT
1.	0%	0%
2.	5%	15%
3.	10%	15%
4.	15%	15%
5.	20%	15%

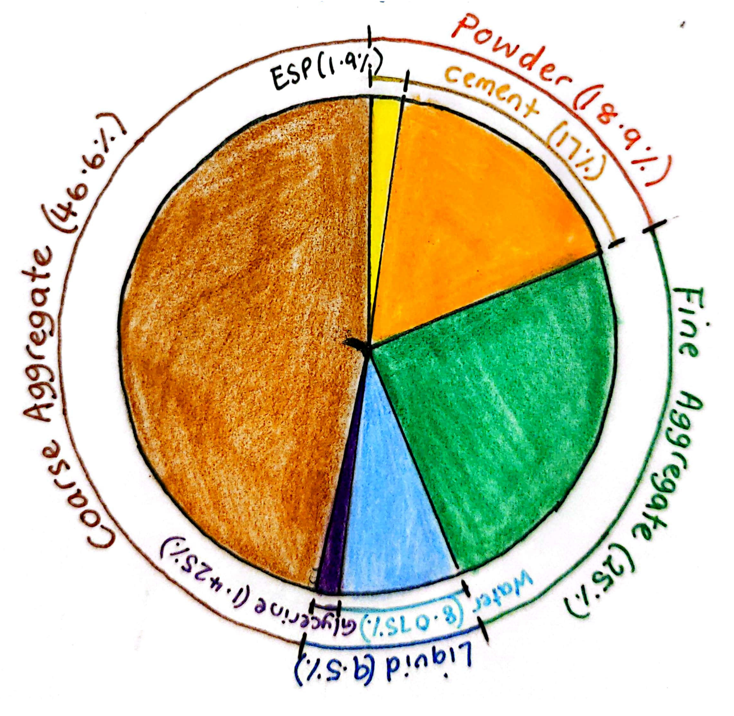
Mix Ratios



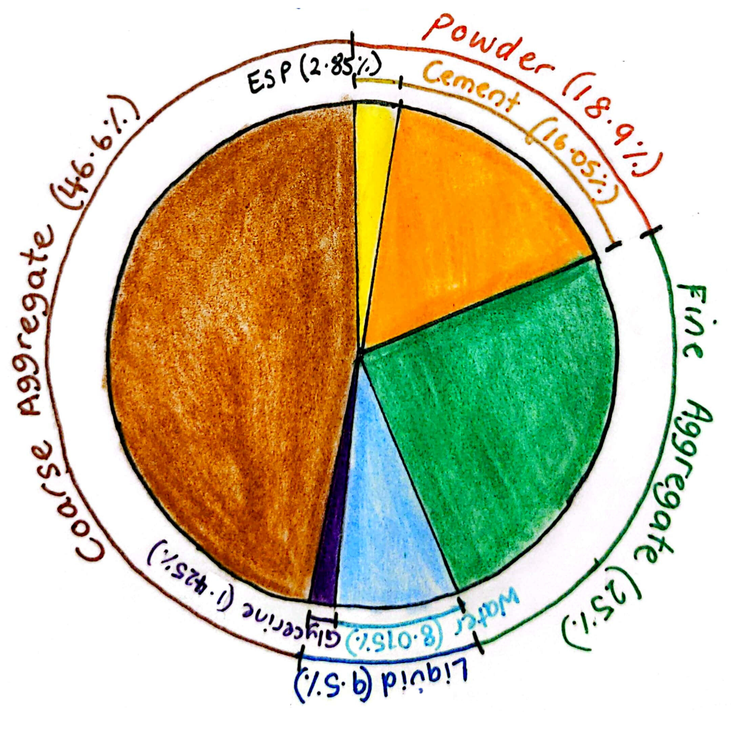
0% ESP Replacement



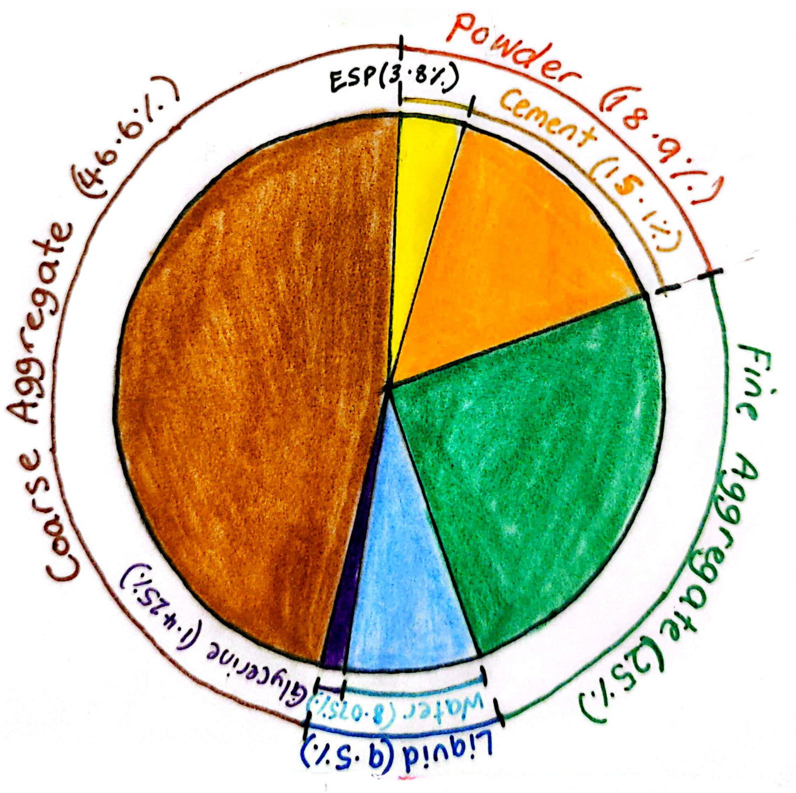
5% ESP Replacement



10% ESP Replacement



15% ESP Replacement



20% ESP Replacement

TESTING & RESULTS

OLLSCOIL TEICNEOLAÍOCHTA BHAILE ÁTHA CLIATH
DUBLIN
TECHNOLOGICAL UNIVERSITY DUBLIN

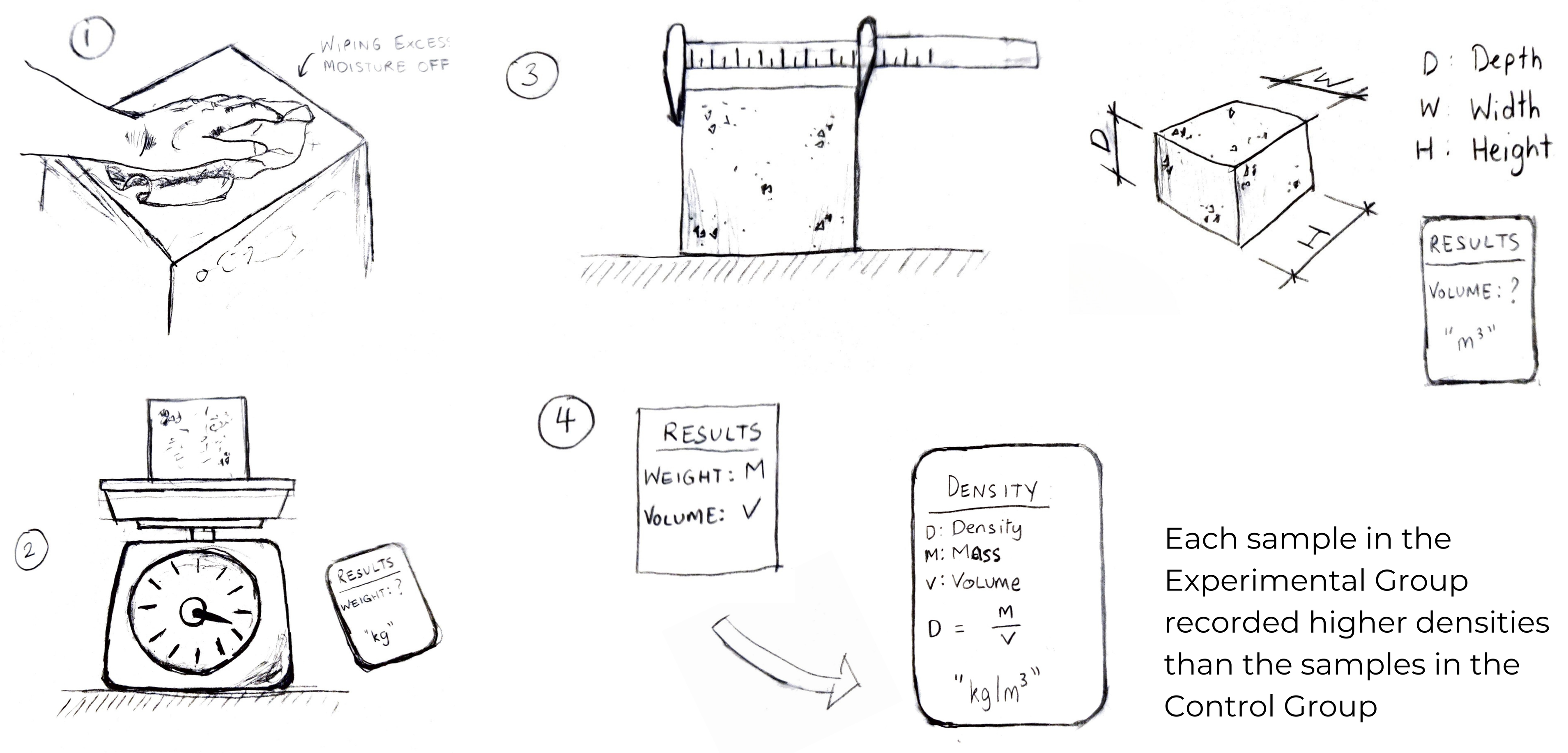
Mix Creation

1. Eggshell Powder Creation

2. Experimental Group Mix Creation

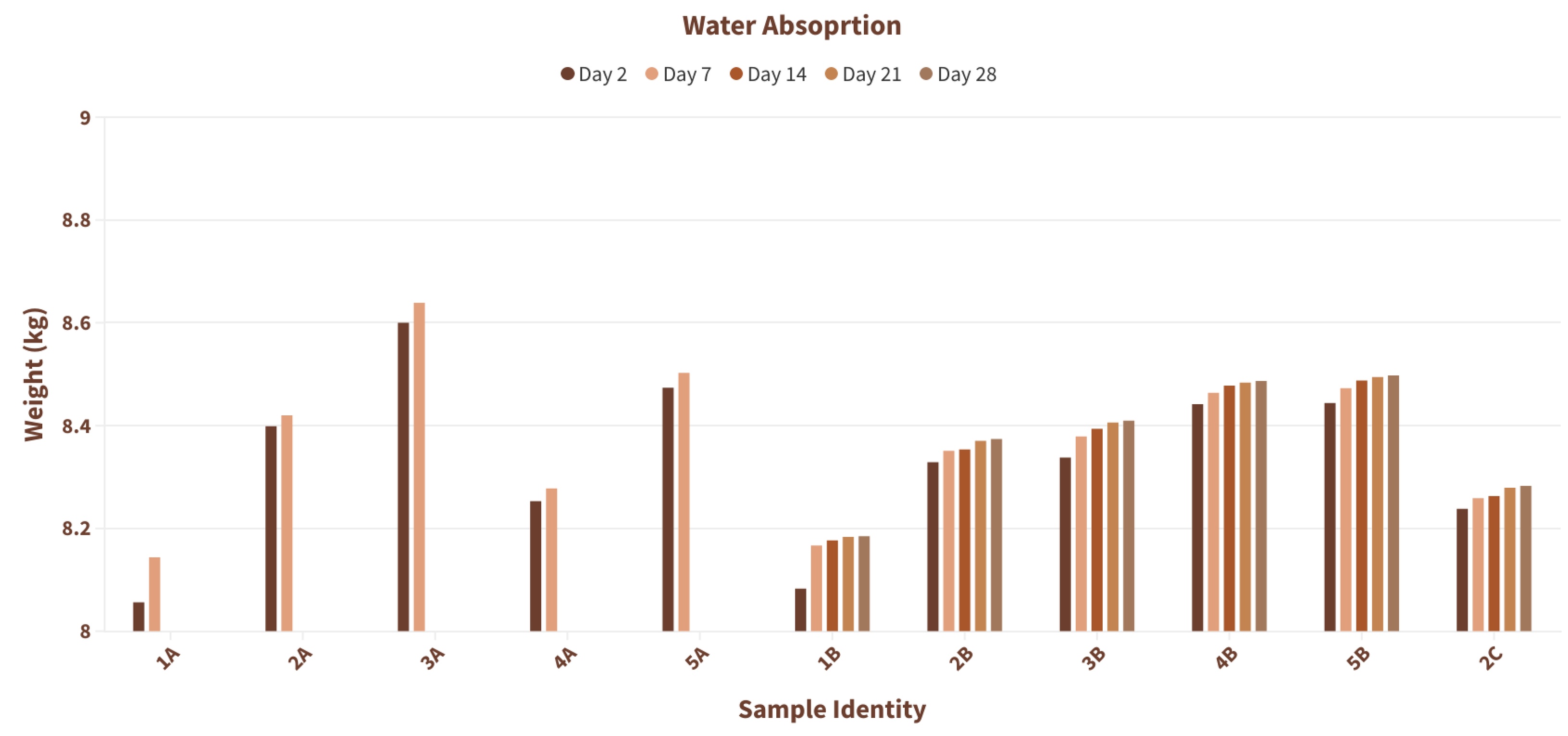
Density Calculations

MIX	SAMPLE	WEIGHT (M)	VOLUME (V)	DENSITY (D)
1	1A	8.144 kg	0.003 m³	2720 kg/m³
	1B	8.185 kg	0.003 m³	2730 kg/m³
2	2A	8.420 kg	0.003 m³	2810 kg/m³
	2B	8.374 kg	0.003 m³	2790 kg/m³
	2C	8.283 kg	0.003 m³	2760 kg/m³
3	3A	8.639 kg	0.003 m³	2880 kg/m³
	3B	8.410 kg	0.003 m³	2800 kg/m³
4	4A	8.278 kg	0.003 m³	2760 kg/m³
	4B	8.487 kg	0.003 m³	2830 kg/m³
5	5A	8.503 kg	0.003 m³	2830 kg/m³
	5B	8.498 kg	0.003 m³	2830 kg/m³



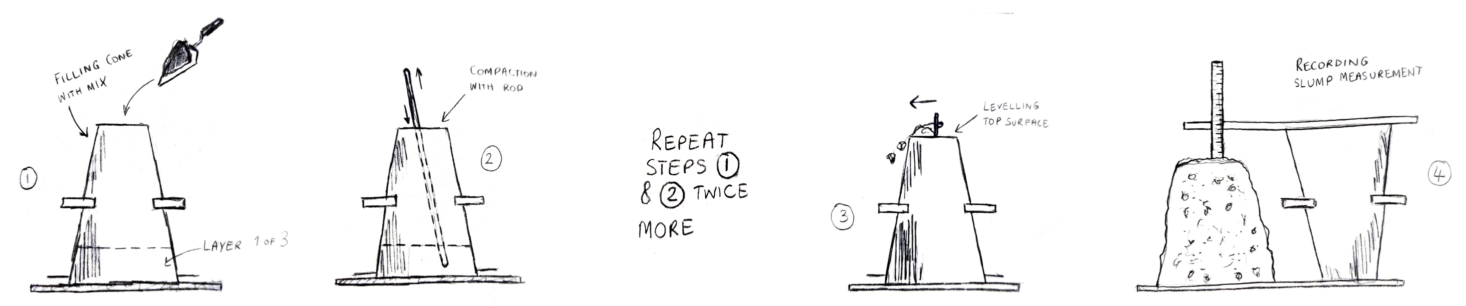
Each sample in the Experimental Group recorded higher densities than the samples in the Control Group

Water Absorption



Sample Number	Day 2	Day 7	Day 14	Day 21	Day 28
1A	8.056	8.144	-	-	-
1B	8.083	8.167	8.177	8.1834	8.1848
2A	8.399	8.420	-	-	-
2B	8.329	8.351	8.354	8.3704	8.374
3A	8.600	8.639	-	-	-
3B	8.338	8.379	8.394	8.4062	8.4098
4A	8.253	8.278	-	-	-
4B	8.442	8.464	8.478	8.484	8.487
5A	8.474	8.503	-	-	-
5B	8.444	8.473	8.488	8.4946	8.4978

Workability Testing

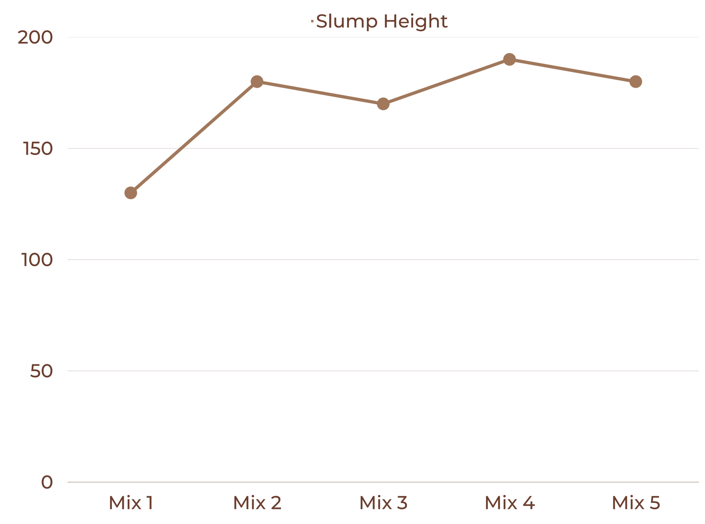


Materials are weighed

Materials are mixed

Materials are poured into slump cone

Height of slump is measured



Mix	Slump	Increase from Control
1	130	-
2	180	38%
3	70	31%
4	190	46%
5	180	38%

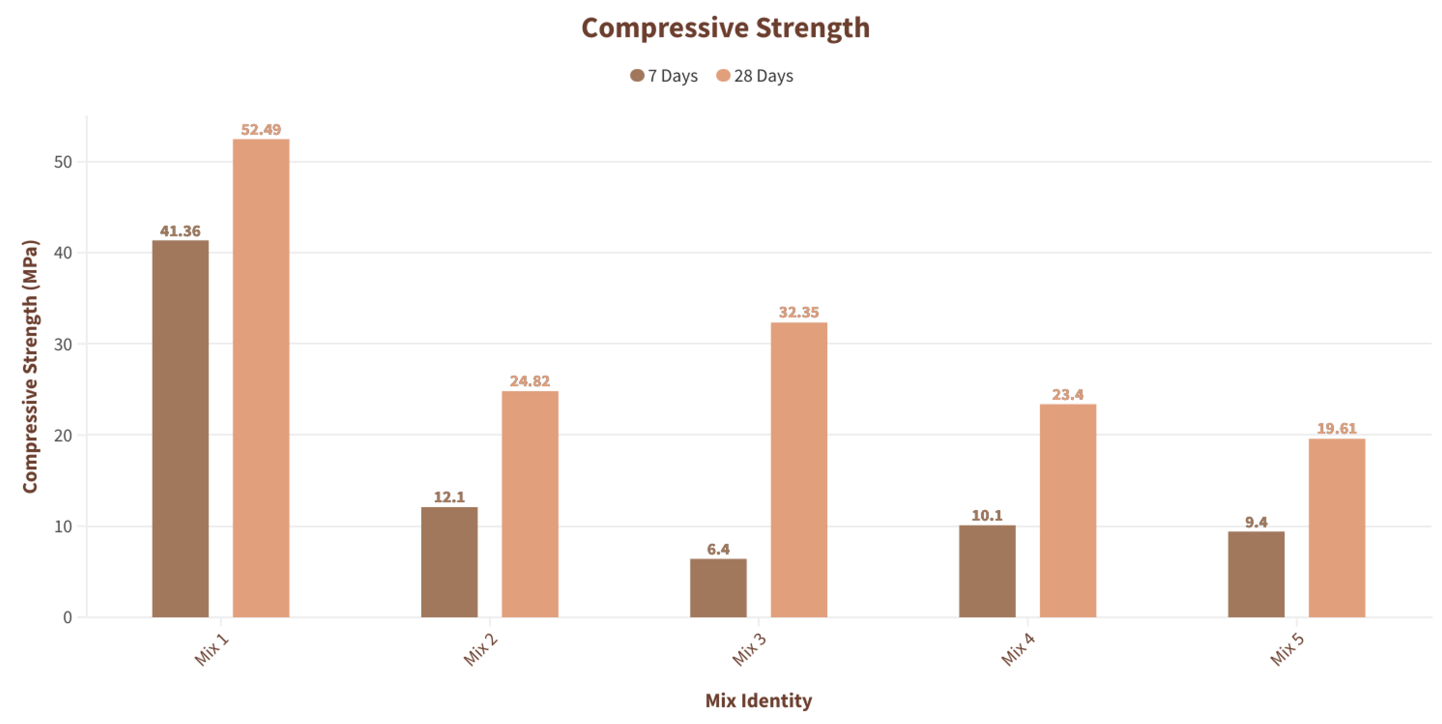
Possibilities for Increased Workability

- The glycerine may have absorbed water resulting in less water absorption by the aggregates initially and keeping moisture in the mix
- The glycerine may have improved the lubrication between the aggregates and particles thus creating less friction and enabling increased movement

From visual analysis, Mix 3 exhibited the most damage after undergoing compressive strength testing. This consists of cracking, chipping and flaking

Mix 2 demonstrated very little external damage revealing only partial flaking on one surface

Compressive Strength Testing



Possibilities for Decreased Strength

- The eggshells did not undergo the calcination process and as a result, the calcium oxide (lime) within was unable to bond with the silica correctly and hindered the formation of C-S-H gel.
- The ESP may not have been fine enough and further studies with finer ESP may show improved compressive strength results.

Material Savings

From all mixes, a total of 17.91kg of cement was used and a total of 1.89kg of ESP replaced cement. This gave a cement saving of 9.5%.

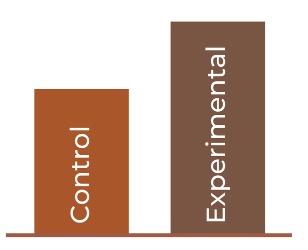
From all mixes, a total of 8.69L of water was used and a total of 1.22L of glycerine replaced water. This gave a water saving of 12%.

Strength Increase

Between 7 and 28 days

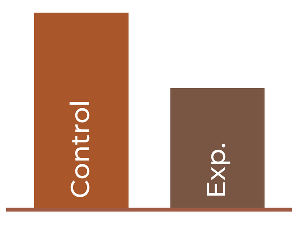
Mix	Increase
1	+21.2%
2	+51.3%
3	+80.2%
4	+56.8%
5	+52.1%

Workability



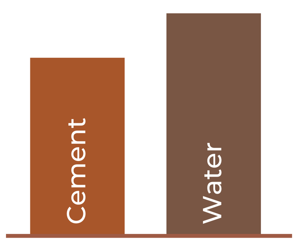
+46%

Compressive Strength



-38%

Material Savings



-9.5% -12%

Brad Whyte
O'Hara C19374483
TECH4200 TDS