Xeroc Recycled Concrete Trial (rev.01)
Windlesham, Surrey

Trial of Xeroc's circular concrete methodology

Contents

Introduction

ISG has worked with Xeroc and Harringtons Builders to carry out a first-of-its-kind trial to use a newly formulated low-carbon concrete. This innovative solution utilises materials from existing concrete that has been demolished and processed into its original elements of sand, aggregate and concrete 'fines'.

Concrete is essential to the built environment, comprising almost half of all building materials used globally due to its strength and durability attributes. Traditionally concrete production makes an outsized contribution to overall carbon emissions through the intensive cement manufacturing process. This includes both direct and indirect CO2 production, through chemical reactions in the product itself and fossil fuels used in the production and transportation of the material. Today there are several different types of cementitious substitutes that can be used to reduce concrete's overall climate impact, such as fly ash and Ground Granulated Blast-furnace Slag (GGBS). Both resources are currently imported to the UK and diminishing in availability.

Using recycled concrete 'fines' in concrete to replace a portion of cement is an opportunity to significantly cut embodied carbon.

Concrete has been largely a linear product, where most 'recycling' involves a downgrade of materials and their uses. This trial using Xeroc's approach to concrete circularity has enabled all the aggregates and sand to be recycled together with a portion of the cement mix, allowing concrete to be made from nearly 90% recycled materials.

Methodology

Overview

The purpose of the trial was to demonstrate the feasibility of circular concrete, taking demolished concrete and processing into fresh concrete using Xeroc's technology. There are several innovative aspects to this:

- Usually, demolished concrete is processed into a fill material such as 6F2. Virtually zero demolition waste is used in permanent or bound applications. This trial uses the demolished concrete to make fresh concrete.
- Ready mix concrete in the UK has a maximum recycled content of 20% of the coarse aggregates, equivalent to about 10% of the total material. In this trial, concrete was made with 83% recycled material (using Cem II as an add-in) and 90% could have been achieved had CEM I been available.
- As a result of Xeroc's separation process, the concrete 'fines' can be used as part of the binder mix. In this trial, across two poured sections, 15% and 30% of cement was replaced respectively with recycled concrete 'fines'.

Initial plans included the removal of three different samples of demolished concrete from different buildings at one of ISG's London projects. In practice, it was only possible to process two of these materials. This concrete was processed to extract high-quality aggregates, sand and concrete 'fines', with as little contamination as possible.

Two batches of trial concrete were poured as temporary paving.

The project spanned six months from June to November 2023

Sample Selection

A site visit was carried out on 26 June 2023 to identify in-situ concrete within planned demolition works. Three suitable samples were identified.

Samples

Sample Number	**Location**	**Year of Pour**	**In-Situ Use**
1	Building H	2023	Thrust Block
2	Building C	1980's	Retaining/Shear Wall
3	Building D	1960's	Mezzanine Slab

In-Situ Samples

Sample 1 – Building H 2023 Thrust Blocks in-situ

Sample 2 – Building C 1980's Retaining Wall in-situ

Sample 3 – Building D 1960's Mezzanine Slab in-situ

Note: Samples 1 & 2 were selected for the final processing. Sample 3 was omitted from the trial.

Crushing Process

Concrete was crushed on site by Harringtons Builders to a size of less than 35mm.

This material was then collected by Xeroc and sent for processing at the pilot plant in North France. Distance from donor site: 200 miles.

At the pilot plant, the material was processed in accordance with Xeroc's Concrete Circularity Methodology (XCCM), a mechanical process involving crushing, screening, and classification. This returns the concrete to its original components, separating the aggregates and sand from the (largely hydrated) cementitious material. The concept of 'smart crushing' is that the binder is weaker than the aggregates or sand. By crushing at a relatively low-pressure, preferential break-down of sand/cement agglomerates is possible, alongside the removal of the cement paste from the surface of the aggregates.

An important factor was ensuring that the input material was kept free of foreign objects, such as brick, glass, wood or rebar, prior to processing to avoid damaging the equipment and as a quality control measure for the recycled aggregates.

Once crushed, material was kept dry to avoid weathering and reducing the amount of energy needed to dry materials during processing.

During this trial, the first material was kept free from contamination with a very small amount of plastic and rebar. However, the second sample was heavily contaminated with plastic, rebar and packaging (see photos below).

Because the pilot plant is used for many materials and process configurations, it was necessary to spend some time and material setting up the system. Excluding material used in the set-up, the material efficiency was 95%. In a full-scale production plant this would approach 99%.

Material Processed

The following table shows the quantity of each sample

Sample	**Collected (kg)**	**Processed (kg)**	**Product (kg)**	**Reason for volume loss**
1	11,330	11,330	10,846	Calibration of equipment
2	8,000	5,500	5,414	Contamination of crushed material

The quantity of recycled sand, aggregate and concrete ‘fines’ after processing of the samples is shown in the table below:

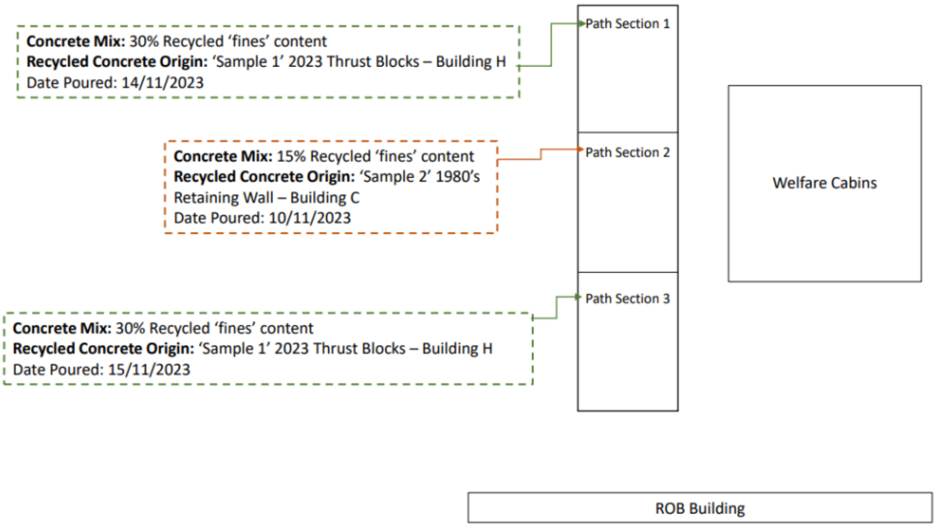
	Sample 1		**Sample 2**	
	Weight (kg)	Ratio (%)	Weight (kg)	Ratio (%)
Recycled aggregates (4mm-16mm)	4,507	41.9	2,426	45.1
Recycled sand (100 µm- 4mm)	4,728	43.9	2,073	38.5
Fines < 100 µm	1,611	14.2	915	16.4
TOTAL	**10,846**	**100**	**5,414**	**100**

With Sample 2, only 5.6 tonnes were processed out of the eight tonnes delivered to the processing plant in France due to foreign objects being mixed in the concrete. Contamination as seen in figure were included within crushed material on site post-demolition, before being transported to the processing plant. This may be result of site activities, waste management, and/or lack of quality checking before leaving site. This resulted in significant time spent manually sorting the raw concrete and there was not enough time in the processing window to process the remaining 2.5 tonnes.

Onsite Trial

Recognising that using Xeroc's innovative approach would not comply with current codes and mix designs, it was mandated that our 'pilot' concrete pour should be applied to a very low risk, temporary works application. Temporary concrete pathways to an onsite welfare compound were selected as an appropriate trial location.

The temporary footpath will be in place for circa 18 months after which it will be broken out. Observations and investigations will be carried out to monitor the condition of the concrete whilst in place. Additional testing of the concrete on demolition is to be agreed.



Mix Design

The mix design was based on standard C30 mix recommendations from the cement producer (Cemex).

Kg/m³	Basic Mix		Xeroc 15%		Xeroc 30 %	
Total Cementitious	387	16.7%	387	16.7%	387	16.7%
CEM II (Rugby Premium)	*387*	*16.7%*	*328*	*14.1%*	*271*	*11.7%*
Xeroc -100µ concrete fines		*0.0%*	*59*	*2.5%*	*116*	*5.0%*
Xeroc 0-4mm sand	726	31.3%	726	31.3%	726	31.3%
Xeroc 4mm-16mm aggregates	1037	44.6%	1037	44.6%	1037	44.6%
Water	173	7.4%	173	7.4%	173	7.4%
Total	2323	100.0%	2323	100.0%	2323	100.0%

Mixing Methodology

Due to the volumes of concrete associated with the trial and logistical constraints it was agreed that all samples were mixed on site using a manually loaded concrete mixer.

Testing Methodology

All components have been tested by G&H in a UKAS registered Lab.

Four cubes of each pathway material were created for testing. Prior to transport to testing laboratories, cubes were stored under typical concrete cube control measures within a cube tank at correct tepid temperatures.

Results from on-site trial

Strength Results

A comparison is made between our results and C30 concrete (used in external walls and paving). C30 has an average strength of 20Mpa at seven days and 30Mpa after 14. The results show that Xeroc's recycled concrete is stronger than typical C30.

Mix	Age Days	7	14	28	56
Xeroc 15%	Date Tested	17/11/23	24/11/23	8/12/23	5/1/24
	Weight (kg)	7.1	7.5	7.5	7.3
	Strength Mpa	31.2	35.5	45.2	51
Xeroc 30%	Date Tested	20/11/23	27/11/23	11/12/23	8/1/24
	Weight (kg)	7	7.9	7.9	7.3
	Strength Mpa	28.7	36.7	43.6	49.5

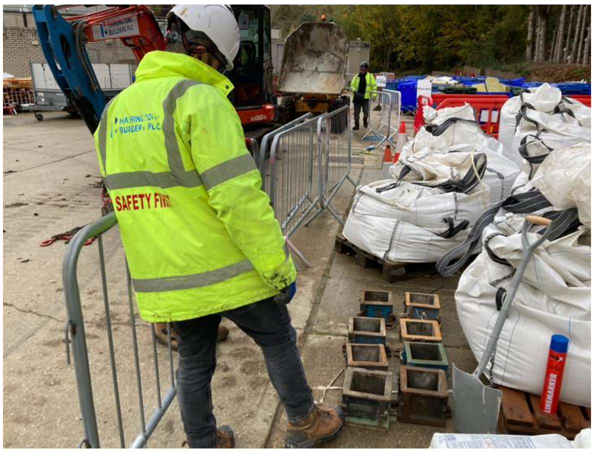


Figure – Cubes for testing being poured on site.

Embodied Carbon

Embodied Carbon calculations have been made by Xeroc, comparing a typical similar concrete mix. Modules A1-A4 were included within calculations.

A1	A2	A3	A4	A5	B1-5	B2	B3	B4	B5	C1	C2	C3	C4
✓	✓	✓	✓										
Raw Material Supply	Transport	Manufacturing	Transport	Construction Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction/ Demolition	Transport	Waste Processing	Disposal
					B6 Operational Energy Use B7 Operational Water Use								
Gate			Site		End Of Life					Grave			

Trial Results

	Recycled Fines	Volume (m3)	Total KgCo2e	KgCo2e per m3	KgCo2e Saving	Difference
Typical C30/40 Concrete	0%	7.0	2,459	351.3		
Xeroc **Trial** C30/40 Concrete	15%	15.1	5070	335.7	15.4	4.4%
Xeroc **Trial** C30/40 Concrete	30%	15.1	4403	291.6	59.5	17%

Carbon savings during full scale plant operations

For this first-of its-kind trial, it was necessary for crush material to be transported a total distance of 400 miles to the operational plant. Following the success of this trial, a mobile model of the plant is proposed for use on the live site, therefore mitigating any emissions associated with transportation of materials. Below is Xeroc's estimate of total embodied carbon associated with the material once the full-scale plant is in operation.

	Recycled Fines	Volume (m3)	Total KgCo2e	KgCo2e per m3	KgCo2e Saving	Difference
Typical C30/40 Concrete	0%	7.0	2,459	351.3		
Xeroc **Full Scale** C30/40 Concrete	15%	7.0	1,905	272.1	79.2	22.6%
Xeroc **Full Scale** C30/40 Concrete	30%	7.0	1,582	225.9	125.4	35.7%

For more detail on calculations please see APPENDIX 2.

Challenges & Next Steps

1. With the small volumes involved, it was difficult to find a 'practical' method of mixing the concrete on site. Volumetric plant methods were investigated, however there were limitations imposed by the suppliers as typically, volumetric plant is delivered will plant being pre-loaded with sand, aggregate and cement. The manual concrete mixer is not ideal in terms of mixing or measurement of quantities, and this is usually compensated by additional cement. Additional quality control will need to be implemented if this method is used again.

2. The cement available was CEM II rather that the planned CEM I. This caused the mix design to be adjusted onsite to use additional cement.

3. The planned depth of the slab was 150mm. In reality, the depth was variable, and in some locations was less than 100mm, increasing the risk of cracking.

4. Key issues to address when scaling up the quantities of recycled material used on the next site include:

    a. Ensuring the 'feed' concrete is clean and not contaminated with plastics, wood, soil and brick
    b. Ensuring that the crushed material is not contaminated from waste materials from site operations
    c. Setting aside storage areas for the recycled sand and aggregates until it is needed for new concrete
    d. Arrangements for the concrete 'fines' to be used soon after production since storage of fines requires silos and will therefore be limited
    e. Identifying applications that can use the recycled concrete (focus on low-risk temporary applications?)
    f. Defining the responsibility for product performance, especially if concrete is made outside the normal product standards

Frequently Asked Questions

1. What kind of concrete / structure is this process suitable for?

- In principle, this approach can be used for all types of concrete. However, to build confidence, we recommend that the circular concrete only be used for non-structural applications.

2. Could this approach create a future safety issue like we have seen with RAAC (Reinforced Autoclaved Aerated Concrete)?

- The testing shows that circular concrete can meet the same performance standards as traditional concrete. Nonetheless, it is prudent to use in non-structural applications until more history is built up about its long-term performance.

3. Is this the first example of demolished concrete being used back in construction on the same site?

- As far as we are aware, this is the first time anywhere that new concrete has been made almost entirely (85%) from concrete demolished on the same site.

4. How much carbon do you expect to save through this type of process?

- Carbon savings of 35% can be achieved through the methods used on this trial. Xeroc is working on other solutions that will increase this further.

5. Does this process create lots of chemical and hazardous wastes?

- The process does not use chemicals and uses only mechanical processing. There is no hazardous waste and very little non-hazardous waste.

6. How does this solution become compliant with British standards / accepted industry practice?

- The Xeroc solution challenges the norm and standards as they both can present blockers to achieve concrete circularity and low carbon outcomes. Xeroc will instead rely on a robust quality management system, checking input materials, process activity and importantly strength monitoring of the outturn concrete. Xeroc will achieve certification to quality/safety/environmental/responsible sourcing standards to enable easier pre-qualification.

Note: This trial has been for temporary usage of concrete in a very low-risk area. Therefore, it does not need to comply with all standards/codes at this stage

7. What are the main benefits to sustainability

- Compared to traditional concrete, significantly less energy is used in production of the Xerox mix. Due to the small quantity of virgin material used (CEM II), impacts of raw material extraction and processing is limited, thus resulting in a calculated **reduction** in embodied carbon of circa 35%.

- This process aligns with a more circular approach to concrete use, reducing the demand on raw material extraction and energy intensive manufacturing processes. Using recycled aggregates, sand and 'fines' in new applications, means that impacts associated with waste management and disposal are also mitigated.

- For future applications, the commercial scale plant will operate **on site** and save the need to transport both demolition waste and raw materials.

- Reduced air pollution associated with concrete production and quarrying vehicle use.
  Again, once scaled up, having plant on site, will also mean less emissions resulting from transportation of materials to different locations.

- Replacement of imported materials such as GGBS with materials generated on site.

Next Steps

This trial has been conducted as a 'pathfinder pilot'. Outcomes of this trial have helped us to understand the process, logistics & collaboration challenges.

- Exploring partnership – Xeroc working with ISG, and interfacing with supply chain
- Identifying benefits of the approach and quantifying
- Understanding challenges and blockers
- Real world trial

<u>Scaling up the solution</u>

- Addressing key learning points from pilot
- Identifying next stage pilot for larger scale trial
- Developing cost model for future application of the technology
- Xeroc – investing in new plant, identifying market scaling opportunities, promotion, and communication of results
- Planned longer term outcomes include Carbon Sequestration as part of the recycling process

- Ready-mix concrete standards include requirements on composition that were defined long before carbon reduction and circularity were important issues. This is changing and indeed some countries have concrete standards that require a minimum recycled content (e.g. 50% in some Swiss standards) rather than the maximum in place under British standards. Xeroc will rely on a robust quality management system, checking input materials, process activity and importantly strength monitoring of the outturn concrete. Xeroc will achieve certification to quality/safety/environmental/responsible sourcing standards to enable easier pre-qualification. In addition, the application of Xeroc products will be primarily in low risk non-structural applications.

Glossary

- **Concrete 'Fines'** – particulate matter that is produced alongside aggregates and sands as result of the Xeroc XCCM technology processing of crushed concrete. These are composed primarily of hydrated cement paste with smaller quantities of rock fines and active cement

- **Binder** - the cementitious mix, traditionally cement but increasingly also containing GGBS, fly ash and limestone, that binds aggregates and sand into concrete

- **Feed concrete** – demolished concrete that has been protected from contamination with other construction waste such as brick, glass and soil

Appendix 1

Offsite Testing – Water Absorption & Size

Separate to the on-site trial, example materials were taken from both Sample 1 and 2 and sent to UKCAS certified laboratory for testing, as well as being tested at our pilot plant.

Samples were tested for:

- Water Absorption
- Size Classification

The results shown below are from the UKCAS certified laboratory

Particle Distribution Sieve (mm)	Cumulative percent retained			
	Sample 1		Sample 2	
	Aggregate	Sand	Aggregate	Sand
16	0%	0%	0%	0%
12.5	0%	0%	0%	0%
10	11%	0%	16%	0%
8	30%	0%	39%	0%
6.3	55%	0%	64%	0%
4	92%	0%	95%	1%
2	99%	21%	99%	4%
1		45%	99%	10%
0.50	99%	67%	99%	21%
0.25	99%	86%	100%	53%
0.13	99%	97%	100%	89%
0.06	100%	99.8%	100%	99.4%
Water absorption	3.9%	6.0%	4.1%	6.8%

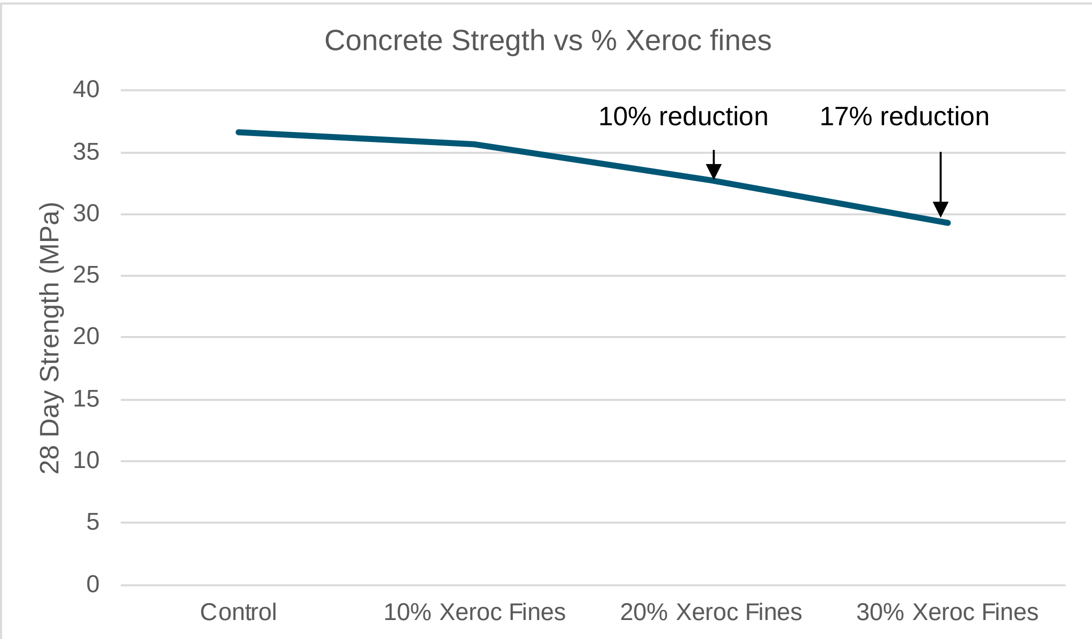
Aggregates used were smaller than typical recycled aggregates used for concrete mix because they were produced in a pilot plant where the equipment has smaller dimensions. The maximum gap setting on the crusher produced this size aggregates. In a production unit, aggregates can be produced to a maximum size of 25mm.

Independent Laboratory Testing – Use of Recycled Fines

Further additional testing included the assessment of the recycled cement 'fines' as binder and the resulting strength variations.

Xeroc's recycled binder was assessed in laboratory conditions by a leading UK concrete company as cementitious replacement in a concrete block paving mix design package. The company found that there was no negative impact on the strength of the concrete at up to 15% cement replacement.

The trial had a control of 6.2% moisture, 60% Ketton CEM I and 40% Purfleet GGBS. It was found that there was a modest strength reduction with an increase of the portion of Xeroc binder.



In the Project Apple Trial, the processed 'fines' were used as cementitious material, where two variations of the mix were trialled.

Appendix 2

Embodied Carbon Calculations

Full scale plant predicted results

						CO2 Kg/t matl		CO2/m3 concrete	
	Material	Qty/m3	Distance	CO2/mile	t/load	Logistics	Embodied	TOTAL	Saving
15%	Cement	328	100	1.99	16	12.42	800	266.47	
	Concrete fines	59	1	1.48	20	0.07	3	0.18	
	Recycled agg	1037	1	1.48	20	0.07	3	3.19	
	Recycled sand	726	1	1.48	20	0.07	3	2.23	
								272.07	**22.6%**
30%	Cement	271	100	1.99	16	12.42	800	220.16	
	Concrete fines	116	1	1.48	20	0.07	3	0.36	
	Recycled agg	1037	1	1.48	20	0.07	3	3.19	
	Recycled sand	726	1	1.48	20	0.07	3	2.23	
								225.94	**35.7%**

Trial results

						CO2 Kg/t matl		CO2/m3 concrete	
	Material	Qty/m3	Distance	CO2/mile	t/load	Logistics	Embodied	TOTAL	
15%	Cement	328	100	1.99	16	12.42	800	266.47	
	Concrete fines	59	400	1.48	20	29.53	8.6	2.25	
	Recycled agg	1037	400	1.48	20	29.53	8.6	39.54	
	Recycled sand	726	400	1.48	20	29.53	8.6	27.68	
								335.94	4.4%
30%	Cement	271	100	1.99	16	12.42	800	220.16	
	Concrete fines	116	400	1.48	20	29.53	8.6	4.42	
	Recycled agg	1037	400	1.48	20	29.53	8.6	39.54	
	Recycled sand	726	400	1.48	20	29.53	8.6	27.68	
								291.80	16.9%

Typical Virgin Materials

					CO2 Kg/t matl		CO2/m3 concrete
Material	Qty/m3	Distance	CO2/mile	t/load	Logistics	Embodied	TOTAL
Cement	387	100	1.99	16	12.42	800	314.41
Aggregates	1037	112	1.48	20	8.27	10.49	19.45
Sand	726	112	1.48	20	8.27	10.49	13.62
RMX transport	2323	10	1.99	12	1.66		3.85
							351.32

Full scale plant predicted results

						CO2 Kg/t matl		CO2/m3 concrete	
	Material	Qty/m3	Distance	CO2/mile	t/load	Logistics	Embodied	TOTAL	Saving
15%	Cement	328	100	1.99	16	12.42	800	266.47	
	Concrete fines	59	1	1.48	20	0.07	3	0.18	
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Sand	726	112	1.48	20	8.27	10.49	13.62
RMX transport	2323	10	1.99	12	1.66		3.85
							351.32

Assumptions Made

Assumptions that have been made for the **Trial Embodied Carbon** Calculations include:

- Fuel used for onsite by the crusher bucket: an average daily amount of fuel was calculated based on monthly fuel use data from Harringtons, the on-site groundwork subcontractor.

- An added 10% to the final kgCo2e/t has been included within results to account of ‘other miscellaneous’ emissions

- Assumption of 10 l fuel used for forklift lifting operations.

Assumptions that have been made for the **Full-Scale Plant – Predicted Embodied Carbon** calculations include:

- To power the mobile plant on site: Assume 70% of construction sites use generators at 1 Kg CO2/KWH (large diesel generator) and 30% use mains electricity supply at 0.21 CO2/Kg for an average of 0.76 Kg Co2/kWh.

- An added 10% to the final kgCo2e/t has been included within results to account of ‘other miscellaneous’ emissions

Conversion Factor References

Factors Used	Reference	Source
Logistics	Department for Energy Security and Net Zero Greenhouse gas reporting: Conversion Factors 2023	https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023
Trial Processing Plant Electricity Consumption	National ad European Emission Factors for Electricity Consumption: tCO2/MWh	http://data.europa.eu/89h/919df040-0252-4e4e-ad82-c054896e1641
Cement ‘Embodied’	Product Specific: Rugby Premium Cement: CEM II	https://www.cemex.co.uk/rugby-premium-cement
Aggregate ‘Embodied’ -for ‘Typical Virgin Materials’	Tarmac EPD 000105	https://tarmac.com/wp-content/plugins/tarmac.com/components/downloads/file-download.php?download_id=6887
Sand ‘Embodied’ - for ‘Typical Virgin Materials’ *Sand is also referred to as ‘Fine Aggregates’ within this EPD	Tarmac EPD 000105	https://tarmac.com/wp-content/plugins/tarmac.com/components/downloads/file-download.php?download_id=6887