concretene™

Innovate UK GraphEnhance
Project ref 10080584
Final report – January 2025

Call: Resource Efficiency for Materials and Manufacturing

Project: GRAPHenhance - GRAPHene scaleup for strength enhanced concrete

Innovate UK project Ref: 10080584

Final report by Alan Beck, Project Manager

Contents

Overview

The overall purpose of the GraphEnhance project was to mitigate emissions from the cement and construction industries via development of a graphene-enhanced admixture that improves compressive strength in concrete. Such an additive allows for reductions in the use of cement for comparable structural performance.

Direct emissions from cement manufacture, combined with concrete-related process emissions (transport, process energy etc), represent >7% of global emissions, necessitating technological solutions to enable the construction industry to meet net-zero commitments.

Therefore, a UK-based solution to reductions in the use of cement in construction offers multiple opportunities:

- to show international leadership on net-zero via mass decarbonisation of the concrete sector
- to achieve significant export revenue and inward investment for UK plc
- to demonstrate valuable return-on-investment for Innovate UK

Project context

Concretene was initially developed via Innovate UK SMART project 99366 (Graphene-enhanced concrete for a Resilient Recovery 2021-22), conducted between The University of Manchester's Department of Mechanical, Aerospace and Civil Engineering (MACE), the Graphene Engineering Innovation Centre (GEIC) and industry partner Nationwide Engineering. This led to commercial-scale pilot schemes in Manchester and Amesbury, Wiltshire, with more than 300m^3 of concrete poured across the three trials.

Despite success in lab trials (+32.5% average uplift in compressive strength in best-performing formulation) and prototype pours (+22% best; +18% average), important considerations for commercialisation regarding supply chain reliability and scalability remained either unresolved or beyond the scope of the project.

Specifically, the GraphEnhance project intended to take forward the work from the SMART grant by answering questions on:

- batch-to-batch reliability of graphene oxide production
- scalability (and therefore cost viability) of graphene nanoplatelet (GNP) production
- environmental sustainability of supply

This allowed us to focus on three of the five areas outlined in the competition scope:

- **Materials for the future economy:** Graphene (including GO and GNP) is a cutting-edge product, with low supply-chain maturity. GRAPHenhance validates a material application (graphene-enhanced concrete) to establish graphene as a valuable product in the future of the UK concrete industry.

- **Resilient supply chains:** by onshoring the manufacture of GO, GRAPHenhance helps the UK transition from dependence on Chinese manufacturing, thus increasing supply-chain visibility and transparency.

- **World-class production:** by paving the way for the manufacture of advanced nano/2D-materials (GO and GNPs) to high-quality standards, with adaptations to meet specific technical requirements, GRAPHenhance establishes the UK as a world-class manufacturer in this space.

Later in the project, we were able to address the two remaining areas, partly as a result of the final demonstrator being in CEM III mix design, rather than CEM I, as stated in the bid (see Appendix 2.9):

- **Smart Design**: more resource-efficient construction design, using less cement and/or concrete, minimising lifetime maintenance requirements

- **Longer in use**: minimising cement and concrete usage and waste, making the supply chain traceable and extending the lifetime of concrete structures.

Objectives

The project's key objectives, stated in the bid, were as follows:

- To establish a standardised UK supply of GO, scalable to >3,000kg/year, at £42/kg
- To optimise UK supply of GNP, at >40,000kg/year, at £30/kg
- To validate performance of manufactured GO and GNP in Concretene with graphene-loading at 3-6%
- To validate the resulting Concretene formulation in an industrial-pilot (transport-sector) against standard durability testing

Project partners

- **Cobmore Holdings (formerly Nationwide Engineering Research and Development)** SME, owner of Concretene technology
- **William Blythe**: leading chemicals innovator, part of Synthomer Group
- **Thomas Swan** (supported by Black Swan Graphene): speciality chemicals manufacturer, developer of GNP IP (IP owned by BSG).
- **(subcontractor) Graphene Engineering Innovation Centre:** nanomaterials commercialisation institute, part of The University of Manchester

Priorities for partners as follows:

William Blythe: piloting (500kg batch reactors) using an adapted Hummer's method (modified addition rate and sequence), standardised to deliver improved batch-to-batch consistency vs existing producers (0.5-2% variance in sp2/sp3-carbon speciation, <0.1% variance in content of sulphur species), enabling greater consistency in Concretene's chemical structure and performance, with best-practice waste-management procedures (on-site waste-treatment plant) to limit pollution vs existing producers.

Thomas Swan: GNP synthesis optimised (target >95% yield), including selection/development of a suitable surface agent to balance exfoliation efficiency with potential surface-agent impacts on the stability/performance of GNP dispersion in Concretene. Scale-up of process to achieve 40-tonne-per-year capacity.

Project structure

The project was split into eight work packages, assigned by initial Project Manager Alex McDermott and managed by Alan Beck (who became PM via request to Grants Services, confirmed 22 Jan 2024):

WP1: Project-Management (Owner: Cobmore)

WP2: Specifications and requirements (Cobmore)

WP3: Lab-based trials (Cobmore)

WP4: Formulation compatibility in concrete (Cobmore)

WP5: Material trials and GO scaleup (William Blythe)

WP6: Material trials and GNP scaleup (Thomas Swan)

WP7: Pilot (Cobmore)

WP8: Communication, dissemination and exploitation (Cobmore)

[see Appendix 1 for final Gantt]

Alan was responsible for day-to-day organisation of the project across formulation and concrete testing laboratories in Manchester and quarterly reporting to Monitoring Officer Urvish Pandya, plus partner meetings in conjunction with technical leadership (Chief Technology Officer Craig Dawson).

<u>Project progress</u>

Q1 (1 Oct - 31 Dec 23)

For Q1 start on 1 October, we assigned and mobilised project teams in our formulation and materials laboratories in central Manchester. We agreed our programme with partners Thomas Swan and William Blythe at the outset, unchanged from that submitted with the bid, specified the materials required and confirmed delivery schedules.

Our formulation team designed and began 'Multivariant Design of Experiment 1' (DOE 1), a statistical framework with which to test many parameters simultaneously, accelerating our understanding of which commercially available graphenes work best in cementitious systems. This includes quality assurance and characterisation of our formulation, including measurements of viscosity (the key to effective dispersion of graphene) and shelf-stability (critical to commercial roll-out).

In the materials lab, our technicians cast and tested concrete and mortar samples with Concretene at different loadings and dilutions, and analysed results to determine the effectiveness of the formulation in delivering performance improvements in compressive and flexural strength.

WP2: Specifications and requirements – completed

WP3: Lab-based trials – commenced and on programme for completion during Q2

WP4: On programme to commence in Q2

[Appendix 2.1 - Technical Report Q1 (Concretene)
Appendix 2.2 - Technical Report Q1 (Thomas Swan)]

Q2 (1 Jan - 31 March 24)

In Q2 2024, our formulation team conducted 'Multivariant Design of Experiment 1' (DOE 1), accelerating our understanding of which materials and processes deliver performance enhancements in cementitious systems. This allowed us to down-select those preferred materials and processes for DOE 2, which narrows the parameter space towards a final, optimised Gen 2 Concretene product.

DoE 1 experimental work took longer than planned due to need for clarification of results (repeats of promising formulations) and need to expand the dataset to fill gaps in the information (e.g. further baseline with superplasticiser work).

A data scientist was hired and started on 18 March. This scientist (Dr Jessica Maldonado) analysed the dataset to inform technical decision making for DoE 2.

Evidence from DoE 1 showed:

- Clear tendencies towards a specification for Graphene Oxide although a further experimentation was required.

- Preferred GNP dispersion specifications to enhance both Compressive and Flexural strength of CEM-I concrete

- Preferred GNP powder specifications to enhance both Compressive and Flexural strength of CEM-I concrete.

- Concretene formulation processing limitations - i.e. formulation is unstable when outside of these limitations.

We found significant efficiencies in our cementitious materials lab cast-and-test process, most notably by adopting plastic cube moulds instead of steel.

This change enabled 2-3x time-saving in stripping and cleaning of moulds, allowing us to reallocate funds from 'Labour' to 'Other' via Project Change Request (PCR accepted 22.03.24, ref. 20240322_10080584_Amendment 01) and use these funds to hire isothermal calorimetry equipment and further accelerate our testing throughput. Calorimetry data enables us to correlate mix design to cement hydration to estimate 28-day strength in 48-hours, thus streamlining Concretene formulation development.

We hired a Research Scientist (Cementitious) – Dr Yasmim Mendonça, started 15 April – an expert in calorimetry to carry forward this work.

Also, within the same PCR, we joined with Alliance Manchester Business School on their International Business Project, the final project for a cohort of MBAs to complete their qualification. The three-month project equates to ~2,500 hours of business consultancy, costs associated only with academic supervision. The final report (deliverable for WP8.2) was delivered on 28 March and feeds into the Business Plan (WP 8.5).

[Appendix 2.3 - Technical Report Q2 (Concretene)
Appendix 2.4 - Technical Report Q2 (Thomas Swan)]

Q3 (1 April - 30 Jun 24)

For Q3 reporting and ongoing, we evaluated progress closely against stated objectives of the project, as follows:

Summary position vs key objectives:

1. To optimise UK-supply of GNP, at >40,000kg/year, at £30/kg(production-cost).

~40t/annum scale-up achieved on schedule by Thomas Swan in WP5; TS reports <£30/kg production cost already achieved in water-based dispersions. Tests ongoing on scaled product towards finalisation of best-performing GNPs end of September.

2. To determine GO-specifications, enabling post-project negotiation for a commercial-supply agreement (WB/Cobmore) for up to 83,000kg/year by 2030.

GO spec scheduled to be finalised end September via DoE#2; post-project negotiation on volume/price: details on pricing v scale was updated in Exploitation Plan Q3

3. To validate performance of manufactured GO and GNP in CONCRETENE with graphene-loading at 3-6%

Progress shown in Concretene Technical Report (Q3, Appendix 2.5)

4. To validate the resulting CONCRETENE formulation in an industrial-pilot (transport-sector) against standard durability testing

We were in talks with UK property developer Landsec to provide a pilot site (these were ultimately unsuccessful)

In Q3 2024, our technical team was strengthened by the hire of Cement Scientist Yasmim Mendonça, the return of Formulation Scientist Teresa Gerace for her second Erasmus scheme industrial placement, and the start of our KTP collaboration with The University of Manchester, with Cement Scientist Xueying Wang starting her role in June. We also took on two new Concrete Technicians in our materials lab – Darrell Connolly and Dylan McDonald. FTE headcount was 19 at 1 July.

WP3 Outputs

The team conducted statistical analysis of outcomes from 'Multivariant Design of Experiment 1' (DOE 1), down-selecting preferred materials and processes from seven parameters for DOE 2 towards an optimised Gen 2 Concretene product:

DoE#1 presented trends in formulation performance as follows:

Material parameters	Observations	Proven ✓ or more work required ➡
Particle size	[redacted]	✓
Layer thickness	[redacted]	➡
Dispersibility	[redacted]	➡ ✓
Aggregation (stability once dispersed in cement)	[redacted]	➡
pH	[redacted]	✓ ➡ ➡
Chemical stability	[redacted]	➡

Our findings were presented to Arup and next steps established for the forthcoming phase of work (DOE#2).

WP4

Agreed next steps:

- Further optimise GNP/GO specifications
- Establish raw material batch-to-batch reliability
- Establish scale-up parameters
- Widen understanding of Concretene impact on mix design specification and process, including baseline for S3 mix

Lost-time issues in WP4

Issue: Switch from S2 to S3 mix design for DoE#2 – as per Arup advice – necessitated re-baselining control mix. Est. time lost = two weeks

Mitigation: use of calorimeter to accelerate testing in DoE#2

Issue: Material supply for S3 mix design – late delivery and issues with quality/consistency of fine aggregates. Est. time lost = 1 week.

Mitigation: new supplier procured, consistency issue solved

Issue: Equipment failure

- main mixer in materials suffered an electrical fault and was down for several days.
- small mixer in formulations lab suffered mechanical fault, returned to manufacturer for repair.
- Est. time lost = ~4 days

Mitigation: in both cases we were able to use shared equipment in GEIC.

WP5/6

William Blythe and Thomas Swan scale-up material analysis was on track to hit milestone end-July.

WP7

Our first option was to proceed with Landsec for our at-scale project

Back-up options were:

ID Manchester (decorative application in Renold Building refurbishment)
Innovate UK KTN: Connecting Innovators in Concrete to Supply Chain programme

WP8

EPD/LCA both in progress with Arup and Thomas Swan. Final assessment of numbers was dependent on final composition of formulation post-September.

FTO/IP – report on freedom-to-operate commissioned from IP laywers Mewburn Ellis – due end Q4, start Q5

Original IP executed in all territories, was published in September.

Comms/workshops – attendance and exhibition on the Graphene@Manchester stand at the Advanced Materials Show at the NEC in Birmingham. Outputs included invitation to join Royce/NPL National Materials Innovation Strategy Working Group and support from Dr Thanuja Galhena, Head of Advanced Materials & Advanced Manufacturing at Department for Business and Trade in application for (non-public) Investment Opportunities Fund (Greater Manchester Investment Zone - £1m-£25m funding)

[Appendix 2.5 - Technical Report Q3 (Concretene)
Appendix 2.6 - Technical Report Q3 (Thomas Swan)]

Q4 (1 Jul - 30 Sep 24)

Summary position vs key objectives

1. To optimise UK-supply of GNP, at >40,000kg/year, at £30/kg(production-cost).

See Q3 (no change)

2. To determine GO-specifications, enabling post-project negotiation for a commercial-supply agreement (WB/Cobmore) for up to 83,000kg/year by 2030.

GO spec finalised end September via DoE#2 (see Technical Report, Appendix 2.7); post-project negotiation (no change from Q3)

3. To validate performance of manufactured GO and GNP in CONCRETENE with graphene-loading at 3-6%

Tests to finalise best-performing TS GNPs for CEM I concrete mix design in laboratory conditions completed in early October (see Technical Report, Appendix 2.7).

4. To validate the resulting CONCRETENE formulation in an industrial-pilot (transport-sector) against standard durability testing

Prototype pour confirmed for Forestry England at Lobslack Seed Distribution Centre, Delamere Forest (see WP7 notes below)

Team additions

In Q4 2024, we took on materials scientist Aneesa Lathif and concrete technician Luke Slipper. Three technicians left the company. FTE headcount 18 at 14 October.

Work package summary

WP3 Complete

WP5 Complete

WP6 Complete (see Thomas Swan technical report)

WP4

DoE 2 complete as per schedule (Sept 24). Testing ongoing to optimise for industrial pour mix design (end Oct for production of materials for pour at w/c 18 Nov)

WP7

Loading bay, 52m^3 pour of low-carbon CEM III concrete. Scheduled for w/c 18 Nov. Project undertaken jointly with Wilmott Dixon, Breedon and Civic Engineers. Testing was scheduled to be conducted on cubes internally and at independent testing house James Fisher.

NB. original plan for Hibberd Development to be subcontract on industrial pilot was at this point unavailable and required change request. Funds were moved into labour, materials and overhead for work on lowering carbon footprint of mix design through use of Concretene (laboratory exercise).

WP8

EPD/LCA both in progress with Arup and Thomas Swan (no change from Q3)

FTO/IP – Original IP executed in all territories. Report on freedom-to-operate commissioned from IP laywers Mewburn Ellis – draft report received for comments. Final report due end October.

Comms/workshops – GEIC exhibition for 20th anniversary of graphene discovery (July); GEIC exhibition for visit of Aramco. Hosted investment team from Mubadala in laboratories. Hosted local-school work experience activity.

Mentioned in *The Times* story on launch of ‘Sister’ (formerly ID Manchester), where Concretene concrete testing lab is sited.

[Appendix 2.7 - Technical Report Q4 (Concretene)
Appendix 2.8 - Technical Report Q4 (Thomas Swan)]

Q5 (1 Oct - 30 Nov 24)

Summary position vs key objectives

1. To optimise UK-supply of GNP, at >40,000kg/year, at £30/kg(production-cost).

No change from Q4.

2. To determine GO-specifications, enabling post-project negotiation for a commercial-supply agreement (WB/Cobmore) for up to 83,000kg/year by 2030.

No change from Q4

3. To validate performance of manufactured GO and GNP in Concretene with graphene-loading at 3-6%

Tests to finalise best-performing TS GNPs in Breedon CEM III (35% GGBS) concrete mix design in laboratory conditions completed Nov-Dec (see Technical Report, Appendix 2.9).

4. To validate the resulting Concretene formulation in an industrial-pilot (transport-sector) against standard durability testing

Trial pours conducted with Forestry England at Lobslack Seed Distribution Centre, Delamere Forest and Clough Cottage Farm, nr Congleton, Cheshire (see Technical Report, Appendix 2.9)

<u>Work package summary</u>

WP 2,3,4,5,6 Complete

WP7 Complete (with variations from Q4 report - and with 7.4 durability testing and 7.5 performance assessment ongoing. See Technical report, Appendix 2.9)

WP8 EPD/LCA both in progress with Arup and Thomas Swan (no change from Q4)

FTO/IP – Original IP executed in all territories. Report on freedom-to-operate received from IP laywers Mewburn Ellis in November.

Comms/workshops – planning for public dissemination activities in Feb 2025 under way. Includes 'external speaker' event at Arup Manchester office (live broadcast to Arup offices UK-wide), Innovate UK event in London and guest-speaking slot with Graphene Council at UK Concrete Show. Press release in conjunction with Breedon scheduled for January.

[Appendix 2.9 - Technical Report Q5 (Concretene)
Appendix 2.91 - Technical Report Q5 (Thomas Swan)]

Conclusion

The headline result of the GraphEnhance project is an industrial-scale pilot in which a ground-bearing slab of graphene-enhanced concrete was laid as Clough Cottage Farm, showing significant uplifts in compressive strength in samples tested at 3, 7 and 28 days.

This improvement in strength opens a pathway to decarbonisation through mix designs that use less cement for comparable performance.

Of equal importance, however, were lessons learned around engagement with companies in the raw material supply chain and with those charged with placing graphene-enhanced concrete. Of particular interest was variation across the construction industry in willingness to explore the art of the possible in technology for reductions in embodied carbon.

Why? Because Concretene is not an off-the-shelf product and should not be treated as such. And until such time as the system is fully understood, empirical testing plus iteration remains the principal method to evaluate performance of graphene in cementitious systems. Testing at scale to produce a large, robust dataset is complex and expensive undertaking, compared to the agility, precision and turnover of testing available in the laboratory.

Thus, partner companies at the delivery end must be willing to be proactive and collaborative in their approach to novel materials in construction to obtain maximum advantage from the technology. The evidence from GraphEnhance suggests some are more collaborative, others more commercial.

Measured against the specified, five-part scope of the project, the impact of GraphEnhance can be summarised as follows:

1. Materials for the future economy
In-project: UK supply-chain for graphene and graphene oxide for the concrete industry established tested.
Next steps: further scale-up to 100s of tonnes p/a as required by developing market for Concretene.

2. Resilient supply chains
In-project: reliance on Chinese raw material supply overcome.
Next steps: Securitisation of supply through multiple supplier testing and agreements.

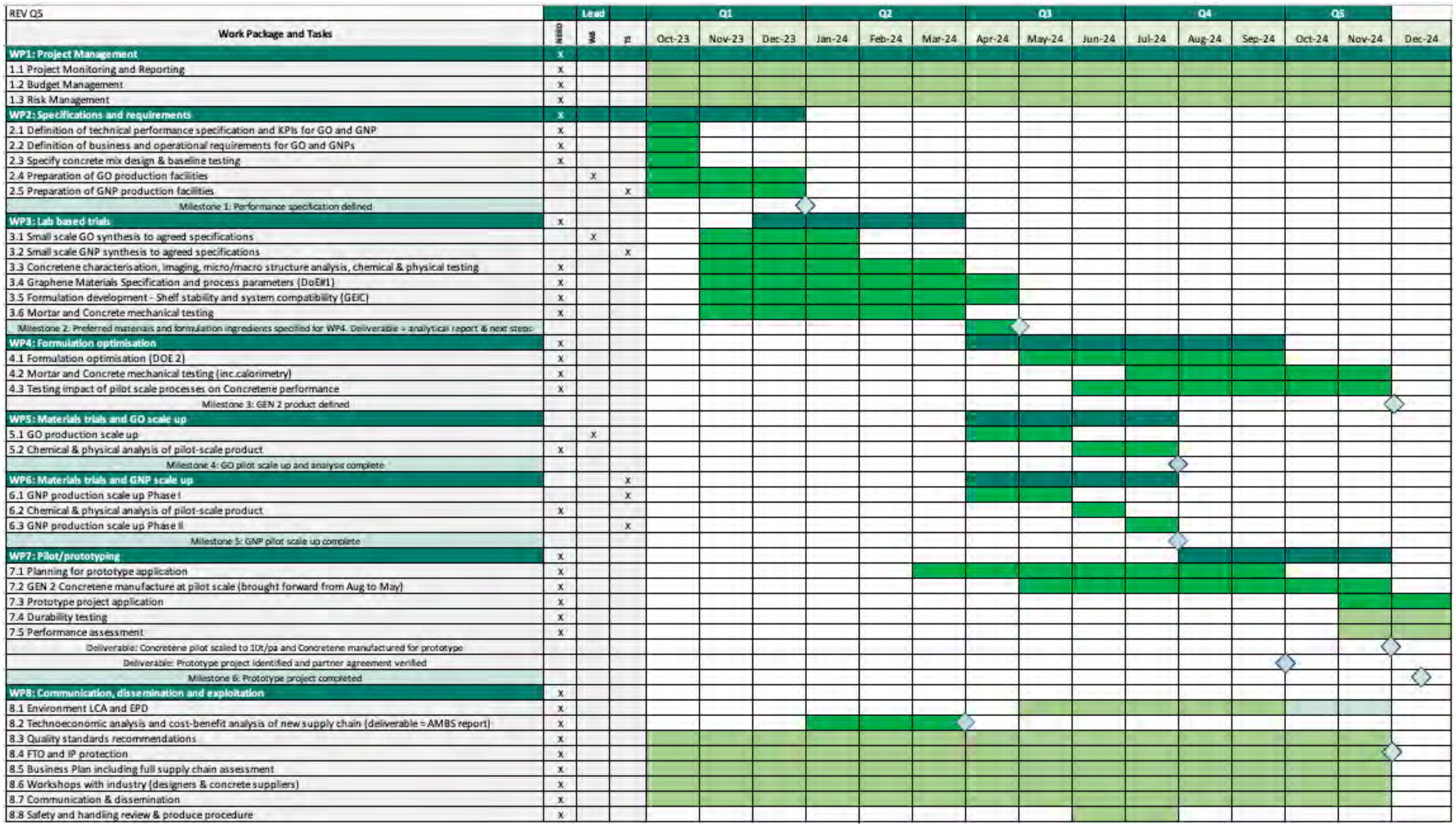
3. World-class production
In-project: identification and fix of variation in raw material supply; specification developed for graphene and graphene oxide for use at scale in concrete.
Next steps: further development of nanomaterial standard with National Physical Laboratory, British Standards, ISO.

4. Smart Design
In-project: switch to CEM III for the demonstrator achieved a world-first, using graphene in a 35% GGBS mix-design, proving compatibility with low-carbon mixes
Next steps: development of yet-lower-carbon mix designs, accreditation and industry roll-out

5. Longer in use
In-project: use of raw materials sourced from waste streams from energy industry extends capabilities in low-carbon systems beyond the lifetime of increasingly scarce supplementary cementitious materials sourced from heavy carbon industry (thermal steel, coal-fired power)
Next steps: durability testing work with BRE and concrete suppliers to prove extendable lifetime of structures built with Concretene

concretene
decarbonising concrete

Appendix 1: project gantt



Appendix 2.1 - Technical Report Q1 (Concretene)

CONCRETENE™

WP3 – Lab Based Trials

Design of Experiments – Materials Specification and Processing Parameters

We have employed a statistical design of experiments to investigate the effect that various material and processing parameters in the manufacturing of Concretene have on the compressive and flexural strength of concrete. The parameters being investigated are:

- Graphene type – either powder or liquid dispersion
- Three different surface agents used in the production of graphene
- Ratios of graphene (GNPs) to graphene oxide (2:1, 4:1, 6:1)
- Purity of graphene oxide – samples from the same batch have been taken from different stages in the purification steps
- Mixing speed during production of Concretene
- Mixing duration of the production of Concretene
- Concentration of graphitic materials (3, 4, 5%)

CONCRETENE™

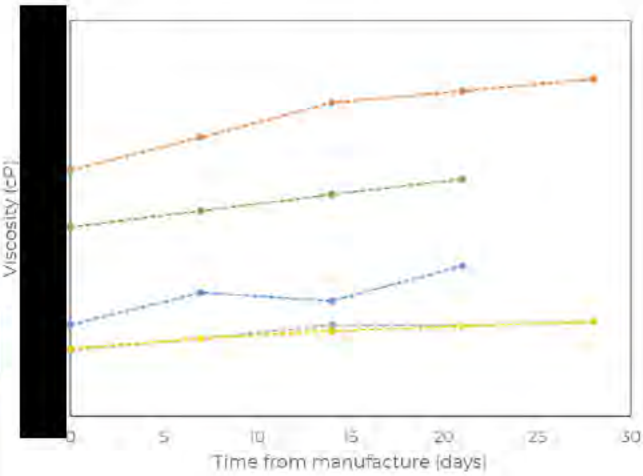
DoE - Stability

Results - Viscosity

The graph to the right compares the viscosity of Concretene containing the high purity GO. All batches of Concretene remain stable throughout a month-long period. No significant increase in viscosity has been observed.

Viscosity is an important metric in determining the dispersity of the Concretene in cementitious systems. Testing is still on-going.

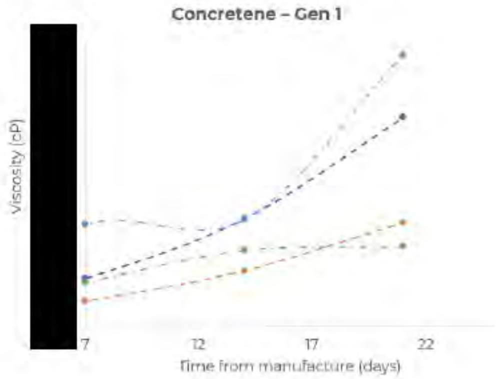
Batch No	[illegible]	[illegible]	[illegible]	GO	[illegible]	Mixing Time (min)	[illegible]
[illegible]	Dispersion	H17	[redacted]				
[illegible]	Powder	H17					
[illegible]	Powder	H17					
[illegible]	Dispersion	H16					
[illegible]	Dispersion	H16					

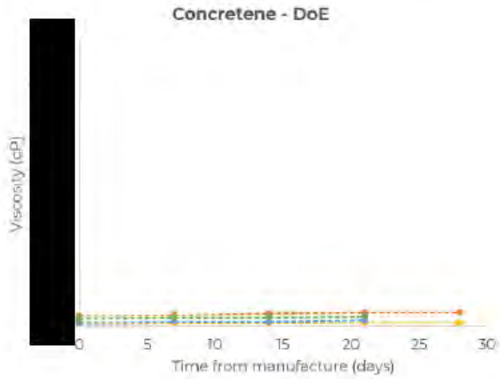


CONCRETENE™ **DoE - Stability**

Results - Viscosity

The graphs below compares the viscosity of Concretene GEN1 made with Chinese GO and Concretene produced for the DoE using William Blythe GO. Using the GO from William Blythe, the viscosities of all batches of Concretene remain stable throughout a month.



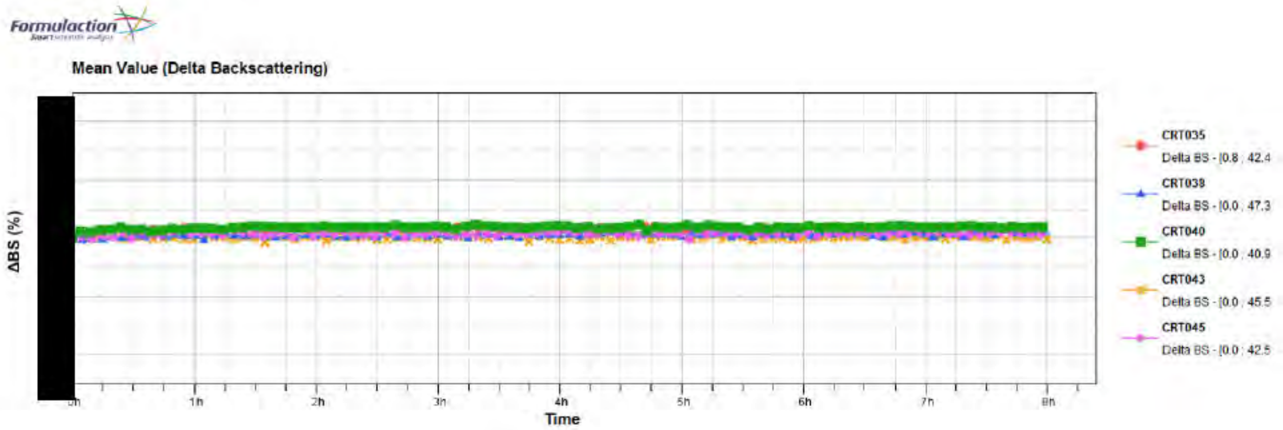


CONCRETENE™ **DoE - Stability**

Results – Turbidity

The graph below shows the stability of various batches of Concretene throughout an 8-hr period on the day of production. All batches, regardless of materials or processing parameters, remain stable. No sedimentation or agglomeration is observed.

Testing is still on-going.



CONCRETENE™ **Conclusions**

WP3 – Lab Based Trials

Bench-scale trials are ongoing. Current results indicate all batches of Concretene made with BSG graphene and WB GO are stable. No agglomeration or sedimentation has occurred.

Compressive and flexural strength testing is currently under way. All experiments must be fully completed before data can be analysed.

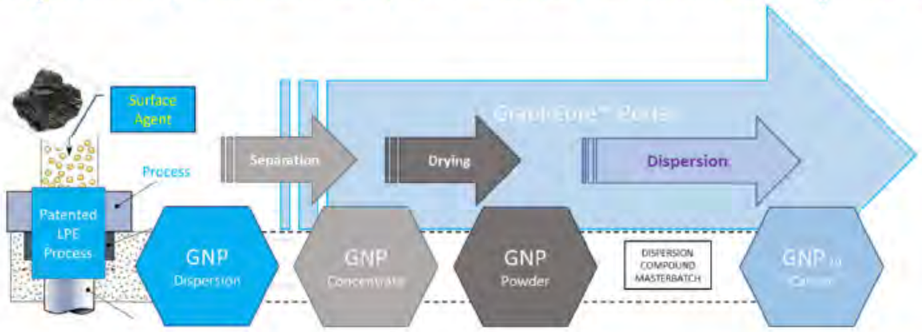
Future Work:
- DoE 1 scheduled to finish mid-February with results to be completed mid-March
- DOE 2 to be designed by end of March for project Q3
- Further characterisation of Concretene - investigation into the morphology using SEM analysis and other techniques

Appendix 2.2 - Technical Report Q1 (Thomas Swan)

Overview

- Description and processing of new HX materials
- Production and analysis
- Comparison to previous concrete product
- Scale up plans and activities

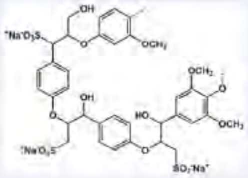
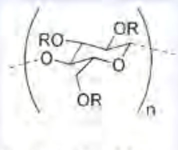
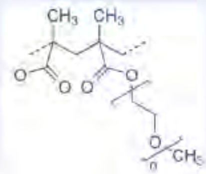
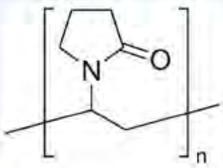
Adaptable, Patented, Modular & Scalable process



BSG Brand	Core	DISPERSION	PASTE	POWDER	APPLICATIONS	GEM - BLACK MASTERBATCH
GraphCore™ GCT	M1	GCT1507		GCT0953	Inks, Coatings	
GraphCore™ 001	F7	GC00101*		GC00104*	Polymer	GC001xx - TPU, PP, PC, PET***
GraphCore™ 002	Hxx	GC00201**		GC00204*	Concrete	
		PRODUCT CODE				

concretene
decarbonising concrete

New materials

Product	GCR94 - H12 (Legacy concrete product)	GCR125 - H15	GCR124 - H16	GCR123 - H17
Graphite source	Byproduct of battery grade graphite production			
Surface agent chemistry	Lignosulfonates 	Carboxymethylcellulose (CMC)  R = H or CH_2CO_2H	Polycarboxylate ether (PCE) 	Polyvinylpyrrolidone (PVP) 

3L scale production (R&D machine)

- GCR123-H17 – M3577-1D & M3577-1P
- GCR124-H16 – M3581-1D & M3581-1P
- GCR125-H15 – M3589-1D & M3589-1P

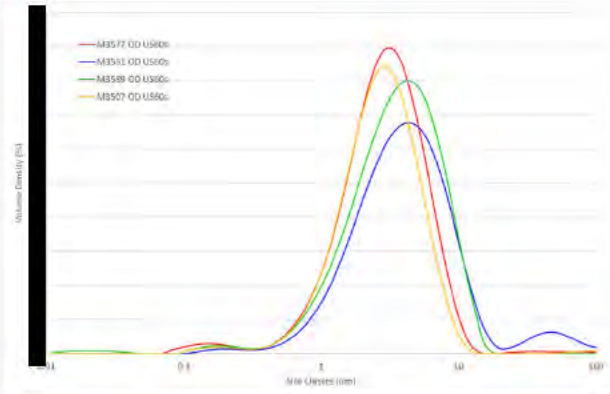
- 200g powder and 2L dispersion dispatched

- All material made using a standard production method
- Process to be further optimized for scale trials.

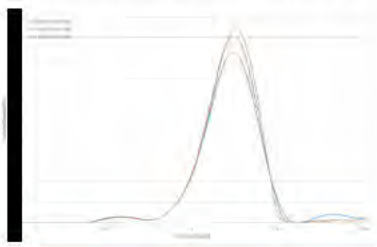
Dispersion PSD (Laser scattering)

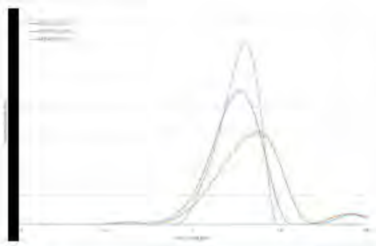
	M3577 – H17	M3581 – H16	M3589 – H15	M3507 – H12
Dv10	1.10±0.00	1.35±0.01	1.19±0.05	1.10±0.00
Mode	3.33±0.18	4.30±0.00	4.30±0.00	2.93±0.00
Dv90	6.28±0.04	9.13±0.29	8.41±0.07	5.72±0.01

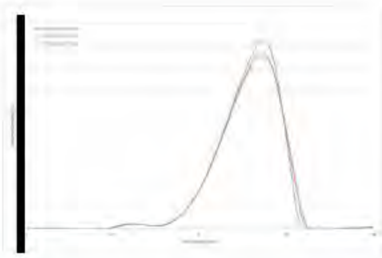
PSD in water as produced



Batch Comparison







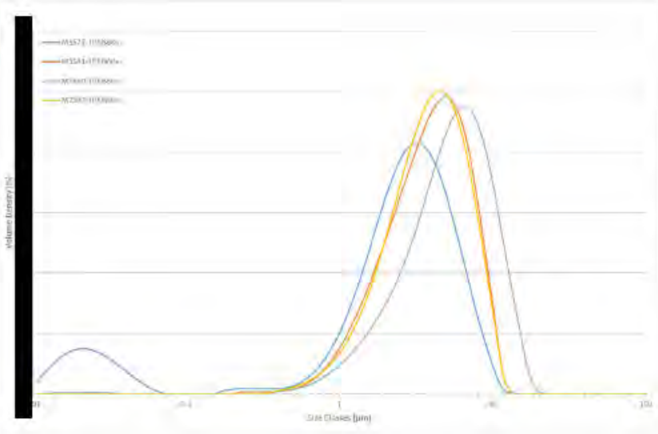
	1	2	3	1	2	3	1	2	3
Dv10	[redacted]								
Mode									
Dv90									

GCR123-H17 (PVP)   GCR124-H16 (PCE)   GCR125-H15 (CMC)

Powder PSD

	M3577 - 1P H17	M3581 –1P H16	M3589 –1P H15	M2587-1P H12
Dv10	[redacted]			
Mode				
Dv90				

Dried powder redispersed in water

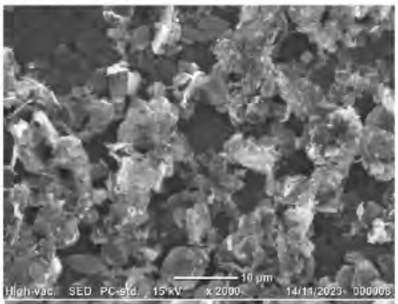


TGA & Bulk Density

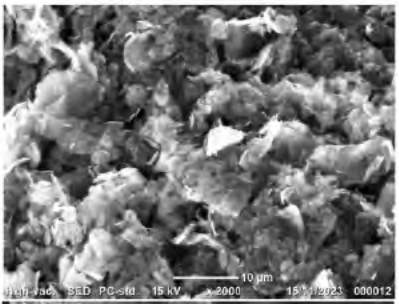
	Method	M3577 – H17	M3581 – H16	M3589 – H15
Moisture (%)	TGA	[redacted]		
Surface Agent Content (%)	TGA			
Residue (%)	TGA			
Bulk Density (g/cm^3)	Scott volumeter (untapped)			

SEM - Powder

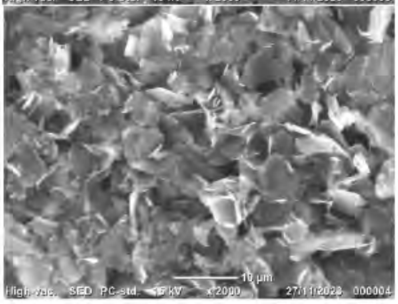
M3577 – H17



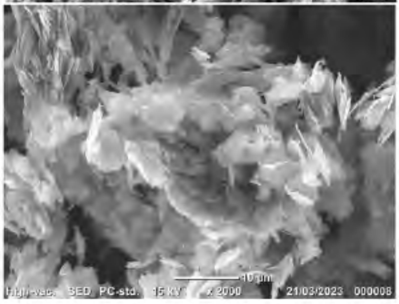
M3581 – H16



M3589 – H15

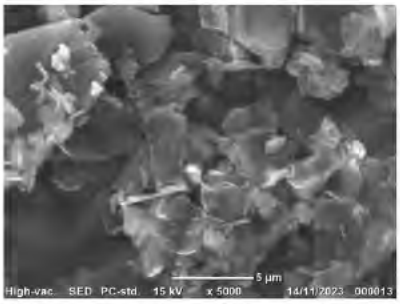


M2598 – H12

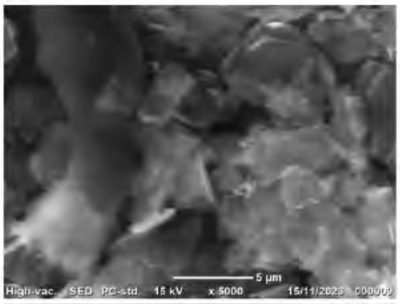


SEM - Powder

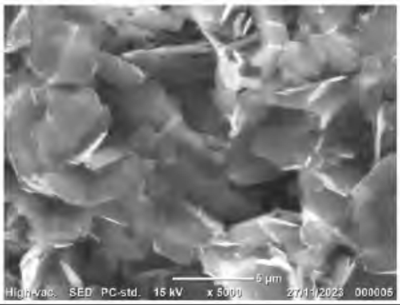
M3577 – H17



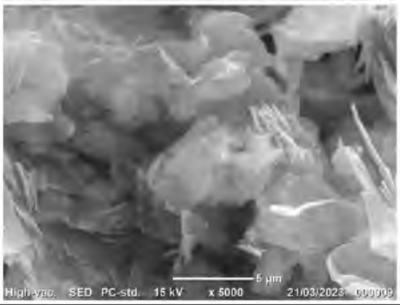
M3581 – H16



M3589 – H15



M2598 – H12



concretene
decarbonising concrete

Next steps

Scale up plan

- Awaiting additional raw materials for 60L runs.
- Optimization runs to be conducted.
- Multiple runs planned to produce sales specification.
- Improvement to powder drying (if required).

QC

- TGA method for H15 requires improvement to compensate for inorganic fractions.

Material to be shipped as required.

- R&D machine produces ~ 3L dispersion/300g powder as required.

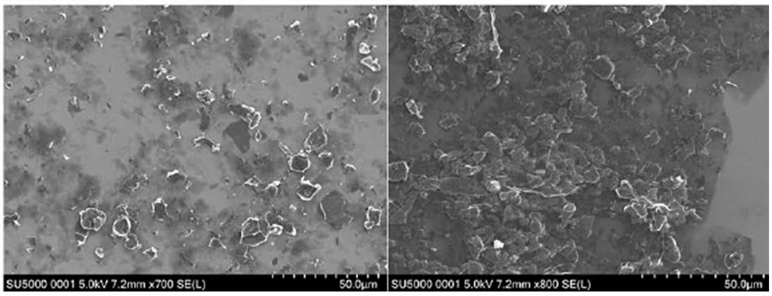
Appendix 2.3 - Technical Report Q2 (Concretene)

Gen 2 development

We have investigated how different constituent materials and mixing processes affect the performance of Concretene in cementitious systems. The methodology of our design of experiment (DoE 1) reduces experimental burden from 200+ experiments to 80. This accelerates our understanding and will allow us to down-select for the next stage of optimisation on completion of statistical analysis (end April '24).

Formulation parameters

- **Stability**: for graphene to remain in dispersion on shelf and in concrete systems
- **Dose**: four different loadings of graphenic materials to investigate performance: [redacted]
- **Blends**: ratio of GNPs to GO to maximise graphene loading with minimal surfactant
- **Particle size**: analysis on SEM (right)
- **Viscosity**: links to effectiveness of dispersibility



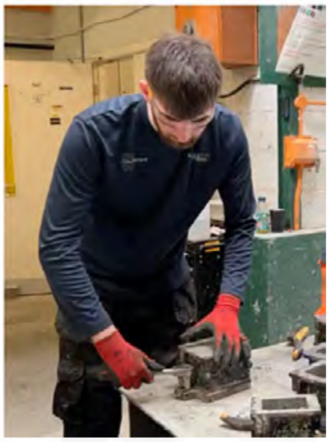
SEM images of interaction between GNP and GO in Concretene formulation, showing patches (left, CRT059 less well performing) vs network (right, CRT043 better performing)

Gen 2 development

concretene

Testing and controls

- **Tests**: 1200 individual samples + 300 controls

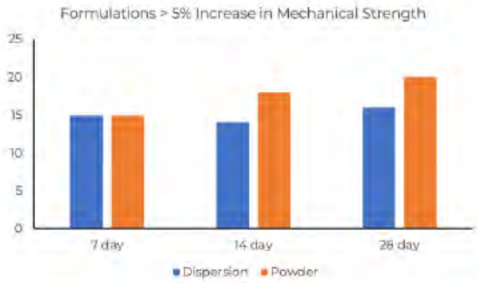


Gen 2 development

concretene

Trends from DoE (to inform down-selection of materials and processes)

- **Graphene oxide**: low-purity GO is less effective than mid- and high-purity. 70% of 28-day samples with >5% uplift contained high-purity GO
- **Dose**: ultra-low dose [redacted] and mid-high [redacted] were best-performing across DoE; 0.12 delivered best single result but less effective through whole study (below right).
- **Mixing speed**: high-speed mixing [redacted] is disruptive to graphene materials with no discernible benefit to formulation
- **Concentration of graphenic materials**: [redacted] concentration is less stable than [redacted] This aligns with literature
- **Powders**: Better overall mechanical performance @ 28 days (above right) but increases cost through drying process and adds health & safety considerations
- **System stability**: optimised GO extends operating window within alkaline environment of concrete from [redacted] mins



% graphene dose	Best uplift @ 28 days	# results >5% @28 days	# results >5% all durations
[redacted]	15.67%	9	35
[redacted]	12.30%	8	30
[redacted]	14.26%	12	33
[redacted]	22.93%	8	23

% uplift in compressive strength by dose

Technical next steps

concretene

- The second round of formulation testing will develop the best performing formulations from round 1, creating multiple repeats to create a more complete data set for compositions with improved performance. Additional blends will be added to the formulation variables, including blended GNP's from synthetic suppliers and GO's from European sources.
- Increased materials testing capacity will drive a fast-track formulation testing for the best performing blends, creating the opportunity to accelerate results testing and blend selection.
- Flexural and durability characteristics testing will be developed in the next period to investigate correlations with compressive strength. New hires increasing technical bandwidth and capacity to bring forward testing regimes and data correlations.
- Results from DOE1 have determined the processing limits for bench-scale production of Concretene formulations. Therefore the best performing Concretene from this programme will be utilised to accelerate scale-up to 15L batch capability. This work is in-line with Thomas Swan being ahead of schedule on there scale-up programme and William Blythe's existing capability.

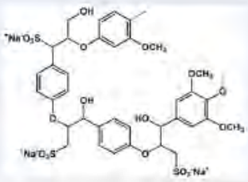
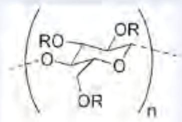
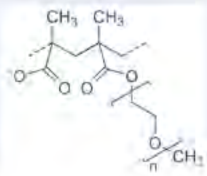
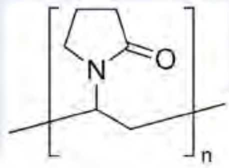
Streamline testing parameters:
- GO purity
- Mixing speed/duration
- Concentration
- GNP surface agents
- % dose

Additives:
- Viscosity modifiers
- pH adjustment
- Stabilisation and shelf-life improvement

Scale-up In-line mixer, 15-litre capacity per run
Parameters :
- Viscosity
- Energy consumption
- Particle size & GNP concentration

Appendix 2.4 - Technical Report Q2 (Thomas Swan)

New materials

Product	GCR94 - H12 (Legacy concrete product)	GCR125 - H15	GCR124 - H16	GCR123 - H17
Graphite source	Byproduct of battery grade graphite production			
Surface agent chemistry	Lignosulfonates 	Carboxymethylcellulose (CMC)  R = H or CH_2CO_2H	Polycarboxylate ether (PCE) 	Polyvinylpyrrolidone (PVP) 

Surfactant development update

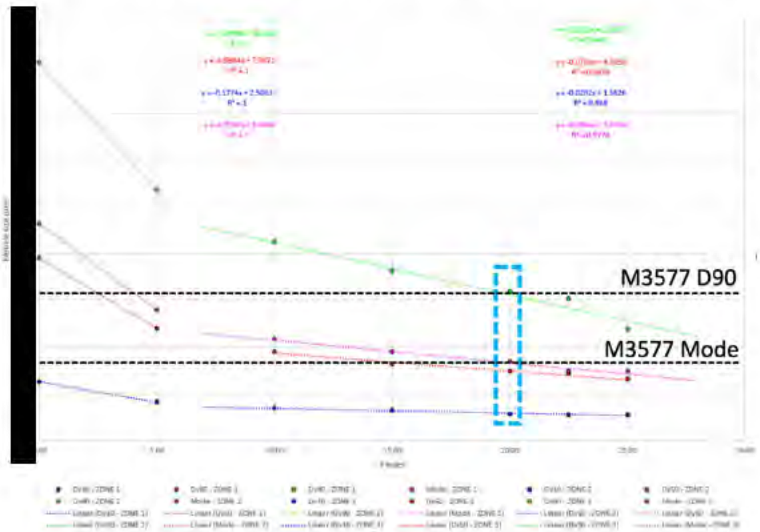
- H15 – based on carboxymethylcellulose
  - Confirmation of scale price from manufacturer.
  - Waiting on distribution contact, manufacturer unwilling to ship quantities <200kg.
- H16 – based on polycarboxylate ether
  - Confirmation of scale price from manufacturer.
  - Raw materials procured for scale trials.
  - Solid weight of product varies from manufacturer batch to batch.
    - Manufacturer unwilling to share specification for solids content. Must be measured batch to batch for surface agent % consistency.
  - Optimisation run complete at 6kg scale and trials started with σ tracking.
- H17 – based on polyvinylpyrrolidone
  - Confirmation of scale price from manufacturer.
  - Distributer relationship developed and product supplied.
  - Optimisation run complete at 6kg scale and trials started with σ tracking.

GNP upscale trials

Upscale trials of H17 performed in February and H16 in March

- Batch scaled from 300g to 6kg per batch
- Run time optimisation performed with two further batches of each produced.

Run optimization of GCR123-H17D

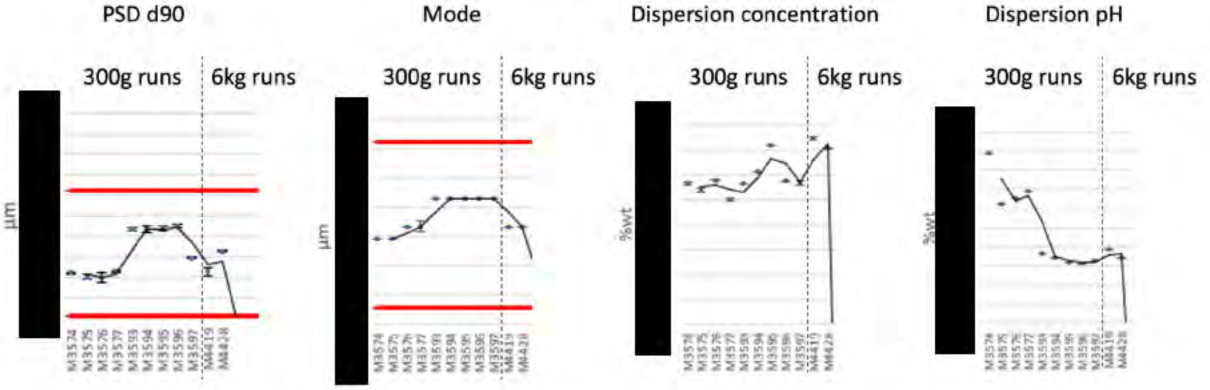


6kg scale run completed tracking PSD as a function of processing time.

Run time selected to match PSD D90 value of M3577.

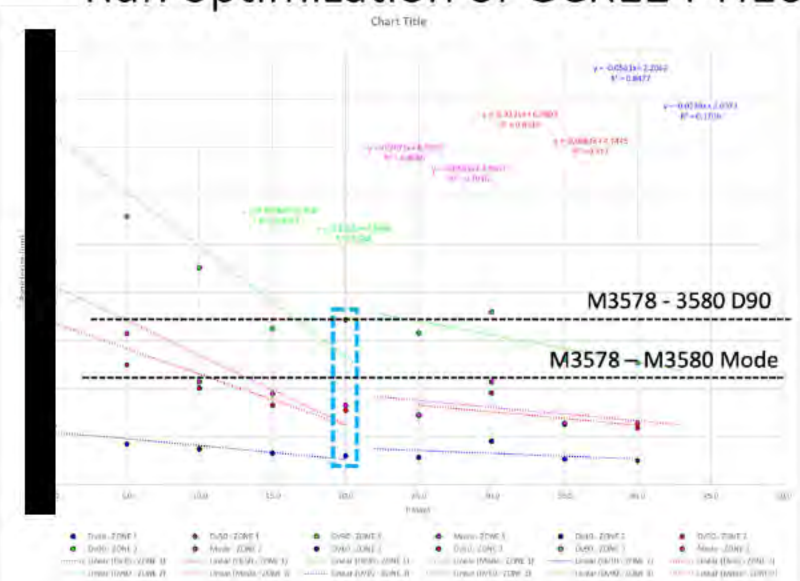
Repeated so far for batches M4419 and M4428

QC Parameter tracking (GCR123-H17D)



As we generate more production data, we will set the specification.

Run optimization of GCR124-H16D

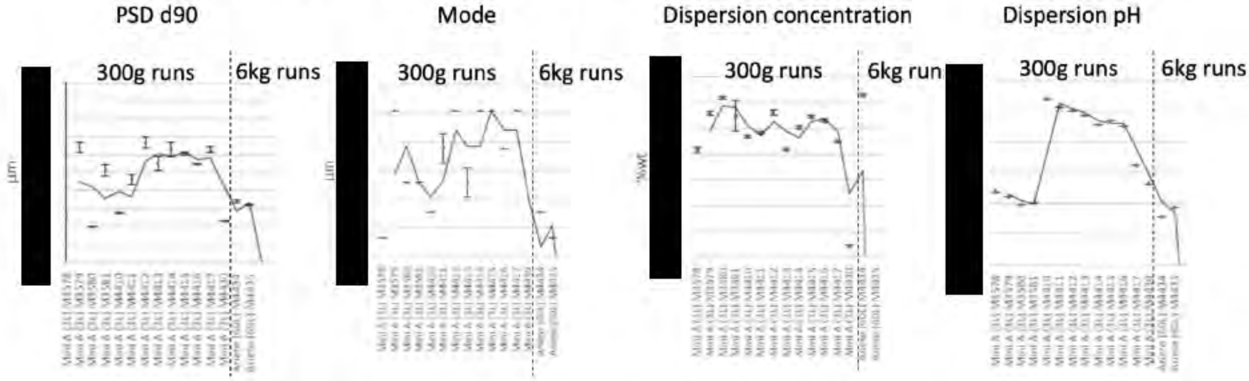


6kg scale run completed tracking PSD as a function of processing time.

Run time selected to match PSD D90 values of batches M3578 - 3580.

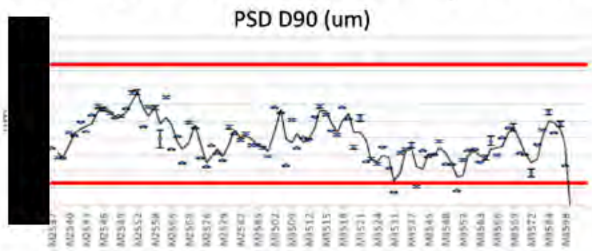
Repeated so far for batches M4434 and M4435

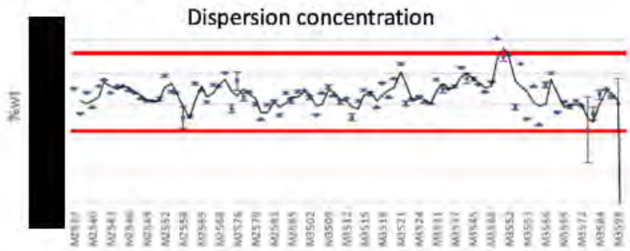
QC Parameter tracking (GCR124-H16D)

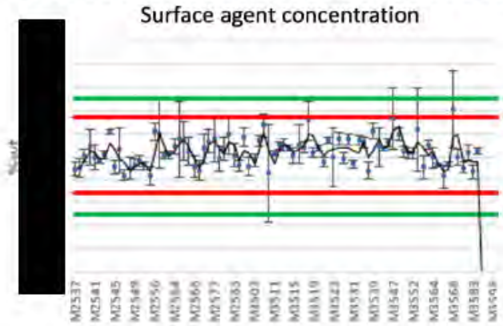


As we generate more production data, we will set the specification.

QC control example GCP104-F7







All measured QC data tracked to generate typical values that form basis of specification.

F7 is an example that we have taken from R&D to pilot and is about to go to full product status.

Appendix 2.5 - Technical Report Q3 (Concretene)

Summary I – Expectations Set

concretene

Following research of the available literature, the following performance for graphene modified concretes could/should be expected:

Performance parameters	Expectation	Standards
Increased compressive, flexural, tensile strength	[redacted]	BS EN 8500, 12390
Accredited early strength enhancement		BS EN 8500, BS EN 934
Reduced shrinkage		BS EN 8500, BS EN 12390
Increased water resistance		BS EN 1881
Improved sulfate resistance		BS EN 196
Improved chloride resistance		BS EN 12390
Improved wear resistance		BS 13892, BS 8204

Results from Phase 1 DoE:

concretene
decarbonising concrete

Materials screening strategy

concretene

To determine GEN2 product using BSG-GNP and WB-GO:

Ph1.DoE	Ph2 DoE	Ph3.Performance testing	Ph4.Performance testing	Ph5.Market testing
Can a stable formulation be made Turbidity/PSD/ Viscosity	Does addition of formulation affect kinetics of paste(s) IsoCalorimeter	Does calorimetry result in high strength &/Or better durability Test for high strength &/or Water uptake	Repeat Ph.3 to understand reproducibility	Accreditation testing? Application specific testing?
All GNP All GO		BSGH15P BSGH12 BSGH16P BSGH15D BSGH16D BSGH17P WBHP BSGH17D	WBHP	

R = Unsuitable
A = Under test
G = Pass to next phase

- Once Ph3. is completed to expectations TRL3 is achieved
- Once Ph4 is completed to expectations TRL4 is achieved
- Once Ph4 is completed to expectations TRL5 is achieved
- For Ph5. dataset may already exist by Ph4 completion
- TRL7 could begin at completion of Ph4

Phase II - Formulations

concretene

Exp. Number	Batch Number	Ratio	GNP	GO
1	CRT145	[redacted]	H17 P	GO4
2	CRT146		H17 D	GO1
3	CRT147		H17 D	GO2
4	CRT148		H16 P	GO2
5	CRT149		H17 P	GO3
6	CRT150		H17 D	GO3
7	CRT151		H15 P	GO2
8	CRT152		H16 D	GO3
9	CRT153		H15 P	GO4
10	CRT154		H15 P	GO3
11	CRT155		H15 P	GO1
12	CRT156		H16 D	GO2
13	CRT157		H16 D	GO1
14	CRT158		H17 P	GO2
15	CRT159		H16 D	GO4
16	CRT160		H16 P	GO1
17	CRT161		H17 D	GO4
18	CRT162		H16 P	GO4
19	CRT163		H16 P	GO3
20	CRT164		H17 P	GO1

Design of Experiments – Phase II

Duration 8 weeks (casting and testing)

Objective
Investigation into the statistical significance of three experimental factors on the mechanical strength of concrete.

DoE – Phase I
- Seven factors:
  - GO purity, GNP type, surfactant, GNP to GO ratio, graphenic concentration, mixing speed, mixing duration
- Results:
  - Ruled out one GNP (H15-D)
  - Ruled out higher mixing speeds, higher mixing durations, and higher graphenic concentrations.

DoE – Phase II
- Three factors:
  - GO (batch-to-batch variation), GNP, and GNP to GO ratio
- Fixed mixing speed, duration, and graphenic concentration

[redacted]

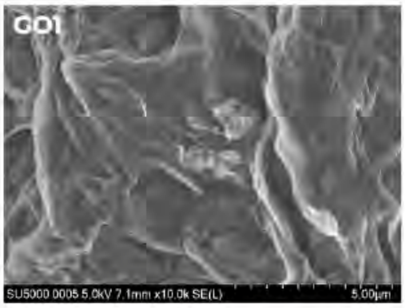
Graphene Oxide

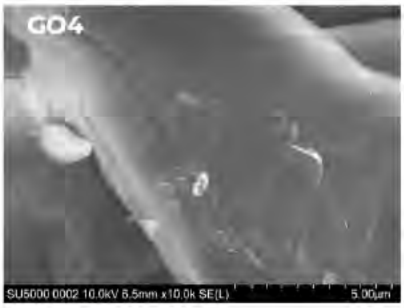
This package of work will compare batch to batch variation of William Blythe GO. Investigation is underway to determine the level of trace metals present in all GO samples. Previous results have been tested and provided by William Blythe.

GO1 has a slightly larger particle size compared to GO2,3. GO4 has a smaller particle size than GO1-3.

Using SEM analysis, smaller platelets were identified in GO4. The presence of smaller spherical morphologies were identified in one sample. Chemical analysis of both samples is under way.

Material	Total Solids (%)	Trace Metals (ppm)	Mn (ppm)	Ca (ppm)	S (ppm)	Cl (ppm)	D10 (um)	D50 (um)	D90(um)
GO1	[redacted]								
GO2									
GO3									
GO4									





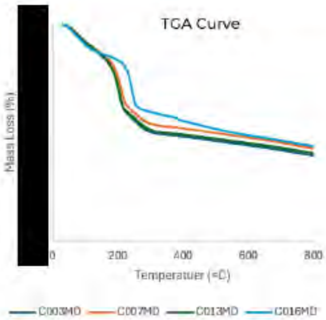
Graphene Oxide

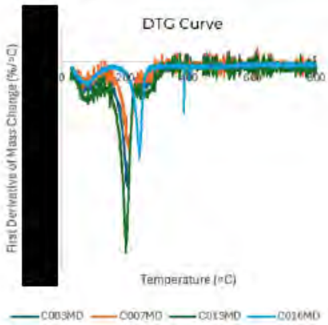
Thermogravimetric analysis was used to determine thermal decomposition and oxidation content.

Samples 1-3 behaved similarly with decomposition temperatures between 201 and 212 ᵒC.

Sample 4 had a higher decomposition temperature possibly indicating a different level of oxidation.

Further investigation is under way.





Material	Moisture Loss Temp (ᵒC)	Decomposition Temp (ᵒC)	Residual Mass
C003MD (GO-1)	[redacted]		
C007MD (GO-2)			
C013MD (GO-3)			
C016MD (GO-4)			

Graphene Nanoplatelets

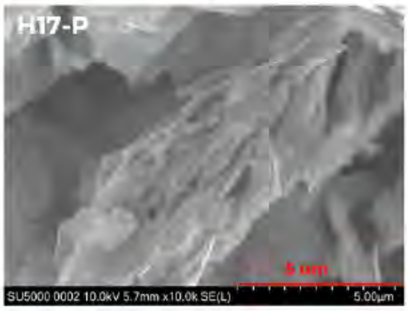
concretene

Material	D10 (um)	D50 (um)	D90(um)
H15-P	[redacted]		
H16-P			
H17-P			
H16-D			
H17-D			

DoE – Phase II explores the use of five different graphene NPs: three powders and two dispersions.

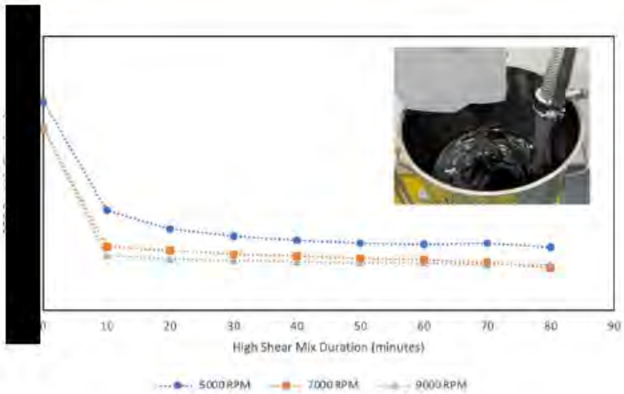
All powder material appear similar in morphology (platelets). Dispersion have smaller D50 particle size compared to their equivalent material in powder form.

Testing is on-going investigating thermal stability (TGA) and platelet characteristics (Raman spectroscopy).



Scale Up - Concretene

concretene



Concretene Scale Up Trials

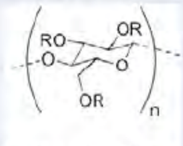
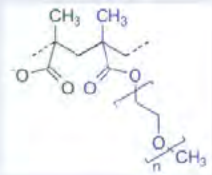
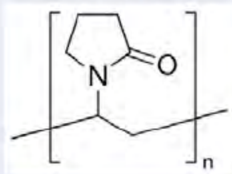
Objective
Investigation of the effect of mixing speed on the particle size of Concretene using the FMX 5 mixer (5-litre batch size).

Outcomes
- Using mixing speeds higher than [redacted] we can decrease the D_{50} particle size of Concretene around [redacted] um after 10-minutes of mixing.
- Fundamental understanding of how particle size stabilizes with time.

Next Steps
- Understanding the energy consumption associated with higher mixing speeds.
- Installation of flowmeter:
  - Investigation of the effect of higher and lower viscosities on flow at various mixing speeds.

Appendix 2.6 - Technical Report Q3 (Thomas Swan)

New materials

Product	GCR125 - H15	GCR124 - H16	GCR123 - H17
Graphite source	Byproduct of battery grade graphite production		
Surface agent chemistry	Carboxymethylcellulose (CMC)  R = H or CH_2CO_2H	Polycarboxylate ether (PCE) 	Polyvinylpyrrolidone (PVP) 

GNP upscale trials

H15

- Distributor set up now in UK to supply product.
- 25kg on order (delivery 6-8 weeks)
- Particle size scoping run completed at 6kg scale
- 1x6kg batch run with surface agent left from initial 300g trials

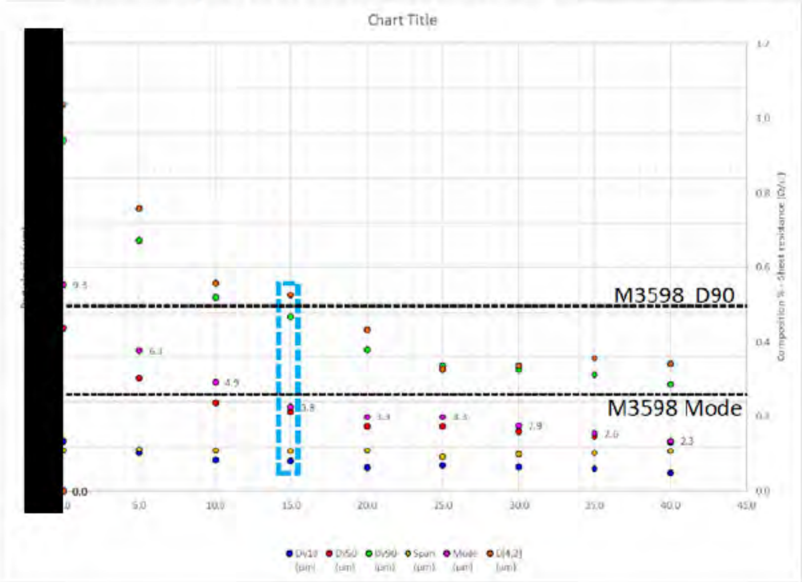
H16

- 6 batches produced to introduce specification if necessary

H17

- No further trials based on demand

Run optimization of GCR125-H15D



6kg scale run completed tracking PSD as a function of processing time.

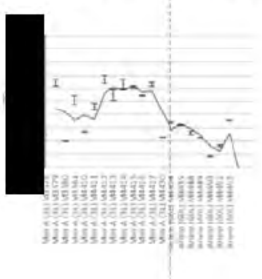
Run time selected to match PSD D90 values of batches M3598 (8.4 um).

Repeated so far for batches M4456 for Concretene (7.6um). Product delivered with material test document.

QC Parameter tracking (GCR124-H16D)

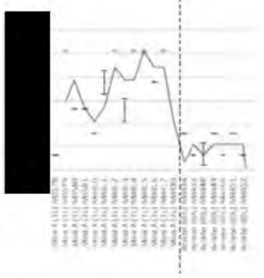
PSD d90

300g runs | 6kg runs



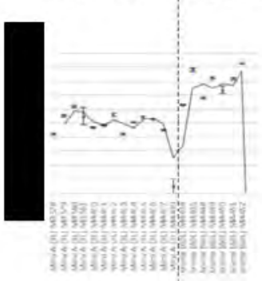
Mode

300g runs | 6kg runs



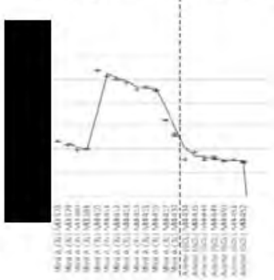
Dispersion concentration

300g runs | 6kg runs



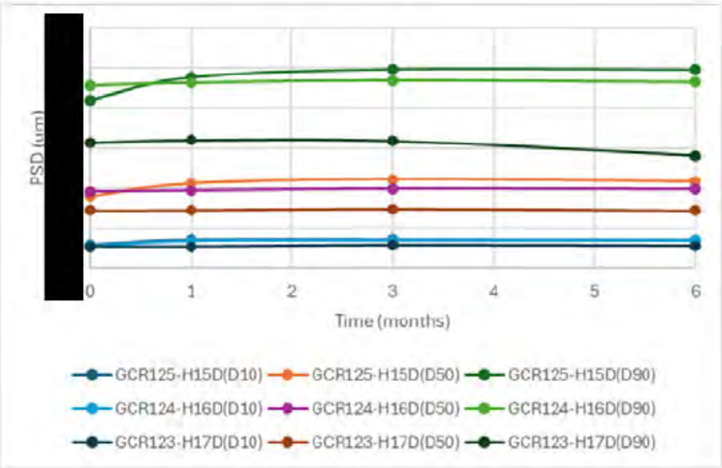
Dispersion pH

300g runs | 6kg runs



As we generate more production data, we will set the specification. Process control and batch yield much better at 6kg scale.

Dispersion stability



Dispersions remixed after different time periods

- H15 sediment firmer than others. PSD D90 produced after remixing increases to 3m and settles.
- H16 shows soft sediment PSD values after remixing relatively consistent.
- H17 show little sedimentation over time. Some decrease in d90 at 6m not understood. Check at 9m.

Current life of dispersion products is 6m. Most water-based superplasticizers have shelf life of 12m but have biocide added.

Appendix 2.7 - Technical Report Q4 (Concretene)

Technical update – Oct 24

concretene

Formulation Laboratory

Our laboratory within the University of Manchester's Graphene Engineering Innovation Centre houses state-of-the-art equipment for formulation and characterisation of nanomaterials in aqueous suspension (Concretene's core IP).

Core function
- Shear mixing of graphene materials into formulation
- Quality control testing (Raman, TGA, SEM, FTIR, EDX)

Latest developments
- Scale-up to 15L capacity in inline mixer (right) with automated data capture
- Tests of chemical additive in cementitious system and effects on performance
- Use of formulation additives to aid dispersivity in concrete.




Materials Laboratory

Adjacent to the Graphene Engineering Innovation Centre, our materials laboratory is housed in the Pariser Building, formerly the purpose-built concrete research facility for the University of Manchester's Civil Engineering department.

Core function
- Cast and test of Concretene formulation in cement paste, mortar and concrete
- Quality control (slump, segregation, air content, environmental control)

Latest developments
- Isothermal calorimetry (far right) for rapid identification of promising formulations
- Accelerated output to >300 samples per week
- Curing control room for 1-day cubes
- Oven for heat-curing process for pre-cast tests



Gen 2 (Phase #1 results to April 2024)

concretene

Compressive strength results vs GO purity – 7, 14, 28 days

7

14

28

[redacted]

Low-purity GO

Mid-purity GO

High-purity GO

Takeaways

- Proof that >20% is achievable with new material supply
- Uplifts seen across dose range (ultra low [redacted] – high [redacted] BWC)
- GO down-selected for purity

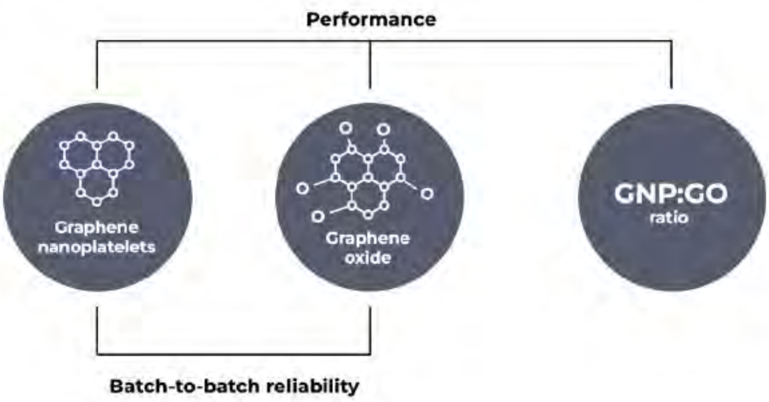
+10-14% with BSG GNPs

+25% best result

Test programme (Phase #2: Jun-Sep 2024)

concretene

- Testing regime repeated from Phase #1 in industrially relevant S3 mix design
- Fixed point of high-purity graphene oxide taken forward from Phase #1
- Key metrics:



Test programme results (Phase #2 results w/c 16 Sept)

concretene™

Compressive strength - % ratio above control

[redacted]

7d

14d

28d

- >10% uplift in performance recorded in S3 (industrially relevant) mix design

Compressive strength - % ratio above control

7d	[redacted]	CRT156	CRT155	CRT154	CRT149	CRT152	CRT145C	CRT157	CRT150	CRT147C	CRT151	CRT158	CRT146C	CRT161	CRT160	CRT153	CRT163	CRT162	CRT164
		CRT148C	CRT149	CRT156	CRT154	CRT150	CRT157	CRT145C	CRT155	CRT161	CRT158	CRT153	CRT147C	CRT146C	CRT160	CRT162	CRT163	CRT151	CRT164
		CRT150	CRT148C	CRT157	CRT156	CRT145C	CRT149	CRT155	CRT147C	CRT151	CRT146C	CRT153	CRT158	CRT161	CRT154	CRT160	CRT162	CRT163	CRT164
		CRT149	CRT150	CRT148C	CRT155	CRT154	CRT157	CRT153	CRT164	CRT151	CRT145C	CRT156	CRT147C	CRT158	CRT146C	CRT160	CRT163	CRT162	CRT161
14d	[redacted]	CRT156	CRT148C	CRT149	CRT152	CRT154	CRT157	CRT147C	CRT146C	CRT158	CRT153	CRT160	CRT150	CRT145C	CRT163	CRT161	CRT151	CRT164	CRT162
		CRT152	CRT156	CRT153	CRT157	CRT149	CRT155	CRT154	CRT158	CRT147C	CRT150	CRT160	CRT161	CRT146C	CRT163	CRT162	CRT145C	CRT164	CRT151
		CRT152	CRT153	CRT157	CRT156	CRT148C	CRT149	CRT158	CRT161	CRT146C	CRT150	CRT154	CRT151	CRT147C	CRT145C	CRT160	CRT163	CRT162	CRT164
		CRT152	CRT149	CRT155	CRT150	CRT158	CRT148C	CRT156	CRT157	CRT164	CRT151	CRT153	CRT146C	CRT147C	CRT160	CRT163	CRT162	CRT161	CRT145C
28d	[redacted]	CRT157	CRT156	CRT149	CRT152	CRT148C	CRT154	CRT145C	CRT150	CRT147C	CRT146C	CRT158	CRT161	CRT151	CRT153	CRT160	CRT162	CRT164	CRT163
		CRT148C	CRT157	CRT149	CRT155	CRT156	CRT158	CRT150	CRT147C	CRT153	CRT162	CRT145C	CRT161	CRT146C	CRT154	CRT160	CRT151	CRT163	CRT164
		CRT155	CRT157	CRT150	CRT146C	CRT156	CRT145C	CRT153	CRT149	CRT148C	CRT158	CRT147C	CRT151	CRT161	CRT160	CRT154	CRT162	CRT163	CRT164
		CRT157	CRT155	CRT149	CRT150	CRT153	CRT154	CRT148C	CRT158	CRT164	CRT158	CRT147C	CRT145C	CRT151	CRT146C	CRT161	CRT160	CRT162	CRT163

- Results ordered high-to-low for comparison with key metrics (following slides)

Compressive strength – by GNP

7d	[redacted]	GNP1	GNP3	GNP3	GNP5	GNP1	GNP5	GNP1	GNP2	GNP2	GNP3	GNP5	GNP2	GNP2	GNP4	GNP3	GNP4	GNP4	GNP5
		GNP4	GNP5	GNP1	GNP3	GNP2	GNP1	GNP5	GNP3	GNP2	GNP5	GNP3	GNP2	GNP2	GNP4	GNP4	GNP4	GNP3	GNP5
		GNP2	GNP4	GNP1	GNP1	GNP5	GNP5	GNP3	GNP2	GNP3	GNP2	GNP3	GNP5	GNP2	GNP3	GNP4	GNP4	GNP4	GNP5
		GNP5	GNP2	GNP4	GNP3	GNP3	GNP1	GNP3	GNP5	GNP3	GNP5	GNP1	GNP2	GNP5	GNP2	GNP4	GNP4	GNP4	GNP2
14d	[redacted]	GNP1	GNP4	GNP5	GNP1	GNP3	GNP1	GNP2	GNP2	GNP5	GNP3	GNP4	GNP2	GNP5	GNP4	GNP2	GNP3	GNP5	GNP4
		GNP1	GNP1	GNP3	GNP1	GNP5	GNP3	GNP3	GNP5	GNP2	GNP2	GNP4	GNP2	GNP2	GNP4	GNP4	GNP5	GNP5	GNP3
		GNP1	GNP3	GNP1	GNP1	GNP4	GNP5	GNP5	GNP2	GNP2	GNP2	GNP3	GNP3	GNP2	GNP5	GNP4	GNP4	GNP4	GNP5
		GNP1	GNP5	GNP3	GNP2	GNP5	GNP4	GNP1	GNP1	GNP5	GNP3	GNP3	GNP2	GNP2	GNP4	GNP4	GNP4	GNP2	GNP5
28d	[redacted]	GNP1	GNP1	GNP5	GNP1	GNP4	GNP3	GNP5	GNP2	GNP2	GNP2	GNP5	GNP2	GNP3	GNP3	GNP4	GNP4	GNP5	GNP4
		GNP4	GNP1	GNP5	GNP3	GNP1	GNP5	GNP2	GNP2	GNP3	GNP4	GNP5	GNP2	GNP2	GNP3	GNP4	GNP3	GNP4	GNP5
		GNP3	GNP1	GNP2	GNP2	GNP1	GNP5	GNP3	GNP5	GNP4	GNP5	GNP2	GNP3	GNP2	GNP4	GNP3	GNP4	GNP4	GNP5
		GNP1	GNP3	GNP5	GNP2	GNP3	GNP3	GNP4	GNP1	GNP5	GNP5	GNP2	GNP5	GNP3	GNP2	GNP2	GNP4	GNP4	GNP4

- Trends identified for better and worse-performing
- 3 GNP variants identified for further consideration

concretene
decarbonising concrete

Compressive strength – by GO

7d	[redacted]	O2	GO2	GO1	GO3	GO3	GO3	GO4	GO1	GO3	GO2	GO2	GO2	GO1	GO4	GO1	GO4	GO3	GO4	GO1
		O3	GO2	GO3	GO2	GO3	GO3	GO1	GO4	GO1	GO4	GO2	GO4	GO2	GO1	GO1	GO4	GO3	GO2	GO1
		O3	GO3	GO2	GO1	GO2	GO4	GO3	GO1	GO2	GO2	GO1	GO4	GO2	GO4	GO3	GO1	GO4	GO3	GO1
		O3	GO3	GO3	GO2	GO1	GO3	GO1	GO4	GO1	GO2	GO4	GO2	GO2	GO2	GO1	GO1	GO3	GO4	GO4
14d		O1	GO2	GO2	GO3	GO3	GO3	GO1	GO2	GO1	GO2	GO4	GO1	GO3	GO4	GO3	GO4	GO2	GO1	GO4
		O2	GO3	GO2	GO4	GO1	GO3	GO1	GO3	GO2	GO2	GO3	GO1	GO4	GO1	GO3	GO4	GO4	GO1	GO2
		O1	GO3	GO4	GO1	GO2	GO2	GO3	GO2	GO4	GO1	GO3	GO3	GO2	GO2	GO4	GO1	GO3	GO4	GO1
		O3	GO3	GO3	GO1	GO3	GO2	GO2	GO2	GO1	GO1	GO2	GO4	GO1	GO2	GO1	GO3	GO4	GO4	GO4
28d		O1	GO1	GO2	GO3	GO3	GO2	GO3	GO4	GO3	GO2	GO1	GO2	GO4	GO2	GO4	GO1	GO4	GO1	GO3
		O3	GO2	GO1	GO3	GO1	GO2	GO2	GO3	GO2	GO4	GO4	GO4	GO4	GO1	GO3	GO1	GO2	GO3	GO1
		O3	GO1	GO1	GO3	GO1	GO2	GO4	GO4	GO3	GO2	GO2	GO2	GO2	GO4	GO1	GO3	GO4	GO3	GO1
		O3	GO1	GO1	GO3	GO3	GO4	GO3	GO2	GO2	GO1	GO2	GO2	GO4	GO2	GO1	GO4	GO1	GO4	GO3

- Best-performing GOs (UK and EEA-sourced) of comparable standard
- Level of Batch-to-batch variability identified for UK supply

Compressive strength – by GNP:GO ratio

7d	[redacted]	LOW	HIGH	LOW	HIGH	LOW	HIGH	MED	MED	LOW	MED	HIGH	HIGH	HIGH	HIGH	HIGH	MED	MED	HIGH	MED
		HIGH	LOW	LOW	HIGH	HIGH	LOW	MED	MED	LOW	HIGH	HIGH	MED	MED	HIGH	HIGH	HIGH	MED	HIGH	MED
		HIGH	LOW	LOW	MED	HIGH	MED	LOW	LOW	MED	HIGH	HIGH	MED	HIGH	HIGH	HIGH	HIGH	HIGH	MED	MED
		HIGH	LOW	LOW	LOW	LOW	HIGH	MED	MED	MED	HIGH	MED	HIGH	MED	HIGH	HIGH	HIGH	MED	HIGH	HIGH
14d		LOW	HIGH	LOW	LOW	HIGH	HIGH	MED	MED	HIGH	HIGH	MED	HIGH	LOW	MED	MED	HIGH	HIGH	MED	HIGH
		LOW	HIGH	HIGH	MED	MED	LOW	LOW	HIGH	HIGH	MED	LOW	HIGH	HIGH	HIGH	MED	HIGH	MED	MED	HIGH
		LOW	HIGH	MED	MED	HIGH	LOW	LOW	HIGH	HIGH	HIGH	LOW	HIGH	HIGH	MED	MED	HIGH	MED	HIGH	MED
		HIGH	HIGH	LOW	LOW	LOW	HIGH	LOW	HIGH	MED	MED	HIGH	MED	HIGH	MED	HIGH	MED	HIGH	HIGH	MED
28d		LOW	MED	HIGH	LOW	HIGH	LOW	HIGH	MED	LOW	MED	HIGH	HIGH	HIGH	MED	MED	HIGH	HIGH	MED	MED
		HIGH	LOW	MED	LOW	LOW	HIGH	HIGH	LOW	MED	MED	HIGH	MED	HIGH	HIGH	HIGH	HIGH	MED	MED	MED
		HIGH	LOW	MED	LOW	HIGH	HIGH	MED	MED	LOW	LOW	HIGH	MED	MED	HIGH	HIGH	HIGH	HIGH	MED	MED
		HIGH	MED	LOW	LOW	LOW	MED	HIGH	LOW	HIGH	MED	HIGH	MED	MED	MED	HIGH	HIGH	HIGH	HIGH	MED

- Clear trend towards higher proportion of GO for better performance

Graphene oxide purity – by supplier and batch

	Elements present	Π	Ρ	Σ	Τ	Υ	Φ	Χ	Ψ
GO	GO-X	1.346	2.095	2.530	8.076	1.678	4.129	41.698	0.231
	GO1	0.380	4.015	1.179	1.773	0.635	1.350	42.658	0.047
	GO2	0.222	3.346	1.022	0.976	0.480	1.087	36.120	0.054
	GO3	0.219	3.900	1.225	1.080	0.601	1.342	36.552	0.054
	GO4-1	0.054	1.198	0.915	0.187	1.061	1.278	28.138	0.075
	GO4-2	0.083	1.348	1.359	0.385	0.868	1.796	33.692	0.099
		0.090	1.260	1.123	0.331	0.736	1.524	36.081	0.058

- Contamination levels of GO: lower = lighter = better
- Negative correlation of two elements with Concretene performance
- Alternative technique (ICP-MS) suggests further correlation with one other element

Six-month activity to Mar 25

Material spec
- Develop performance spec for range of graphene materials.
- Raw materials supply spec set for graphene oxide

Dispersion
- Further development of methods for effective dispersion of graphene and graphene oxide

Scale-up
- Build and commission mini-pilot plant to deliver formulations for clients' scaled trials and manufacturing data to standardise process

Accreditation
- Work with Arup towards specs for harmonised European standard for concrete admixtures BS EN 934-2

Isothermal calorimetry

- Equipment funded by Innovate UK grant
- Enables analysis of heat of hydration as indicator of performance in setting time and final strength
- Better understanding of additional processing steps required to specify GNPs as part of Concretene development

- Cement scientist Yasmim Mendonça is expert in calorimetry work in cementitious systems

Appendix 2.8 - Technical Report Q3 (Thomas Swan)

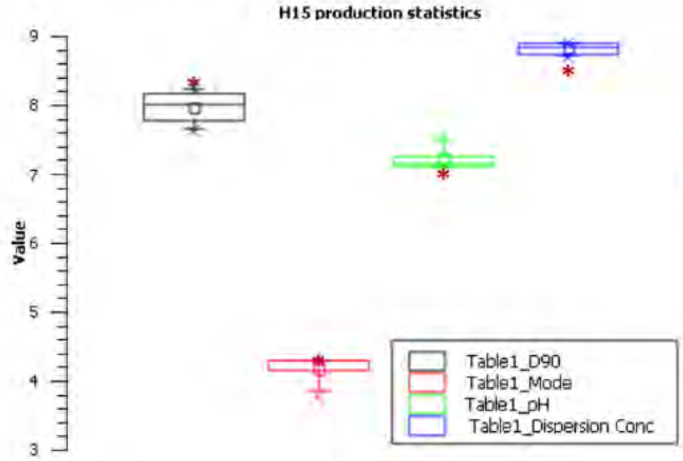
Update

H15
- Surface agent now 25kg stock at Consett site.
- Surface agent price confirmed for 24/25
- 3 x 6kg runs completed in Q4

H16
- Surface agent price confirmed for 24/25
- 1 x 6kg runs completed in Q4

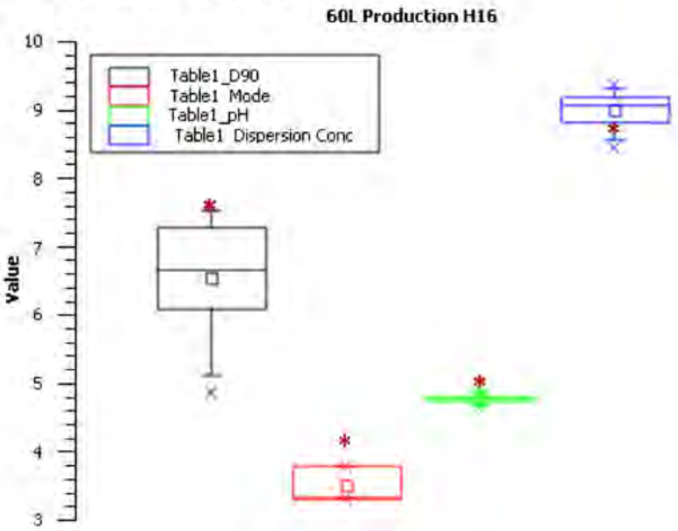
H17
- Surface agent price confirmed for 24/25
- 2x 6kg runs completed in Q4

H15 60L production



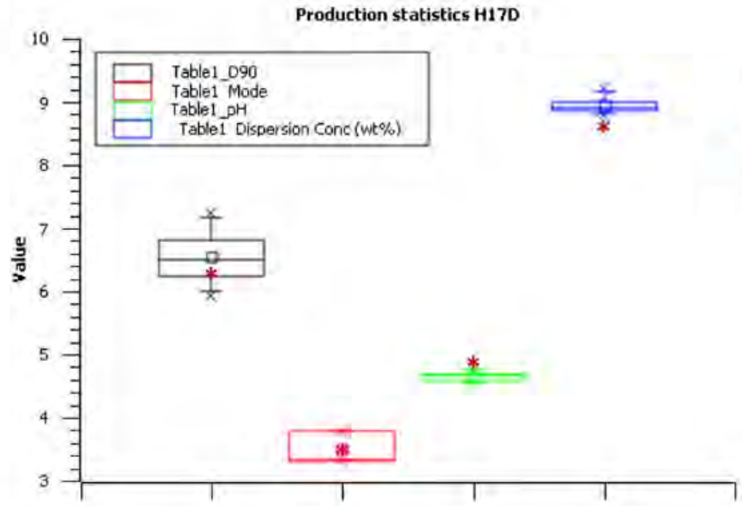
* Values compared to M3589 (DoE batch)

H16 60L production



* Values compared to M3581 (DoE batch)

H17 60L production



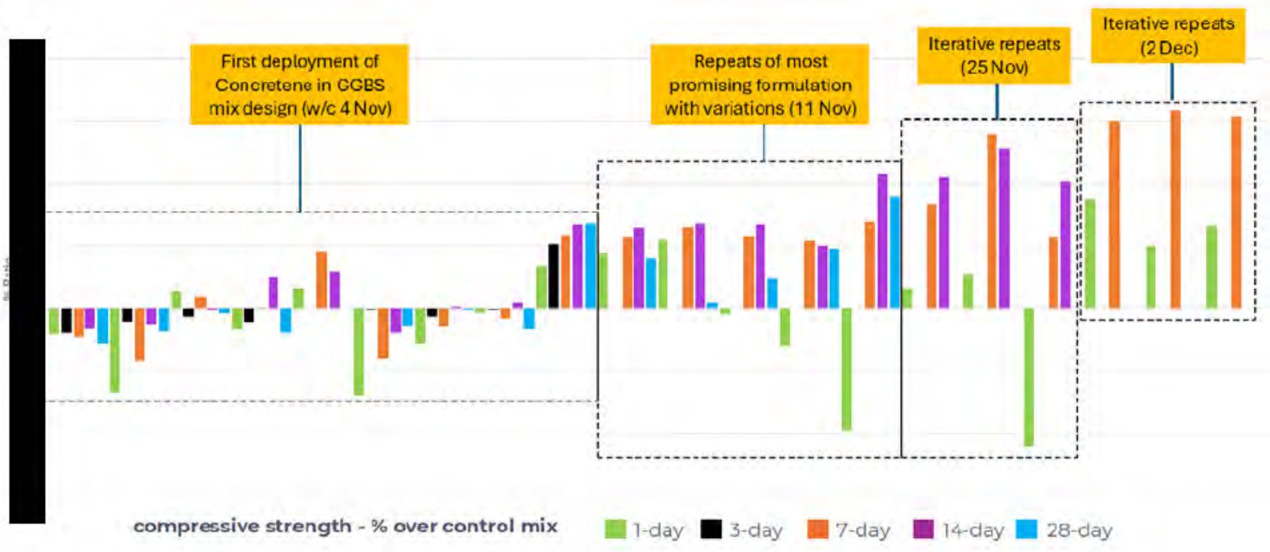
* Values compared to M3577 (DoE batch)

Budget in Q4/Q5

- NPL analysis (subcontracting) underway – material selection was expected Jul/Aug and analysis was expected to be complete in Q4. Work in progress but incomplete, invoice in Q5.
- Equipment parts (materials) ordered - delayed to Q5 due to supplier delays. Expect to buy another set by Q5 end to replace spares used in project.
- Balance of materials spend to get spare tank mix impeller. Major delay to production if this was to go.
- Expect to be under budget on travel. Original budget involved partner visit, travel and stay. Due to quarterly meetings being primarily online budget will go unused.

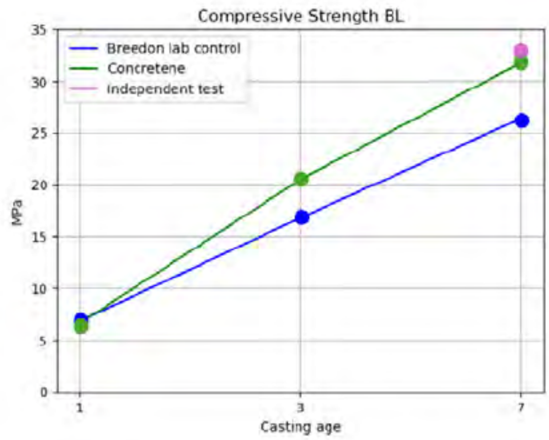
Appendix 2.9 - Technical Report Q5 (Concretene)

Lobslack lab results (4 Nov – 2 Dec)



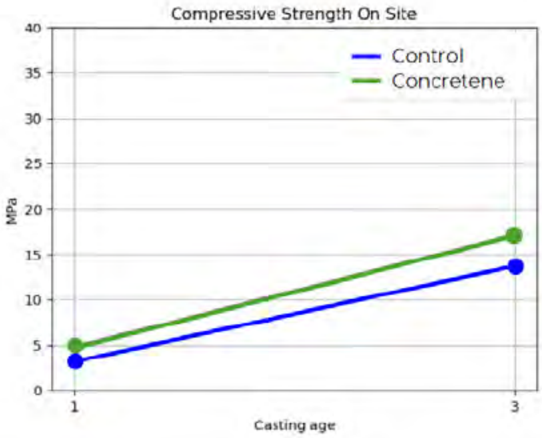
Lobslack field results

- 1-day trial results ~equivalent to Breedon lab control performance (6.6MPa vs 6.8)
- 3-day trial results up **+22%** on Breedon lab control (20.5 MPa vs 16.8)
- 7-day results up **+20.5%** on Breedon lab control (31.8MPa vs 26.4)
- Independent 7-day result from trial pour (conducted by James Fisher Testing) up **+23.5%** on Breedon lab control (32.6MPa vs 26.4)



Clough Cottage field results

- 1-day trial result – Concretene is **+41%** on site control (4.51MPa vs 3.19)
- 3-day trial result – Concretene is **+24%** on site control (16.93 MPa vs 13.61)



NB. Three-day results only were recorded at time of Q5 meeting. Subsequent testing recorded uplift of 14% at 7 days and 7% at 28 days.

Appendix 2.91 - Technical Report Q5 (Thomas Swan)

Update

H15
- 2 x 6kg produced for demonstration pour
- 15kg ordered in Q5

H16
- No batches produced
- 15kg ordered in Q5
- Batches for demonstration taken from stock

H17
- No batches produced
- 15kg ordered in Q5
- Batches for demonstration taken from stock

No material selection was made by Concretene by Q5 end (Nov 2024)

Project learnings

- We have been able to use a waste stream of the battery industry to make a GNP usable in concrete
  - Battery industry is forecast to grow considerably so we are able to reuse increasing waste streams in concrete industry.
- Have found a successful GNP surface chemistry/chemistries usable in concrete.
- Our high intensity shear process handled an untested feedstock well.

Next steps

- Upscale drying capability if powder is preferred.

Budget in Q4/Q5

- Labour
  - Funds transfer from materials to fund activities in Q5 surrounding materials required for demonstration pour.
  - Underspend due to reduced material volume requested from Concretene than expected from Q4 meeting for demonstration pour.
- Subcontracting
  - Underspend due to original quotations from NPL covered single samples per request.
  - Subcontractor time savings made due to multiple samples submitted per request.
- Materials
  - Original budget covered machine component spares due to use of new unknown graphites of lower purity (for cost).
  - Materials ran better than expected so only one spare set was required in project.
  - Reduced workload in project from original scope on R&D machine required no spare sets to be used.
- Travel
  - Original budget was planned for in person quarterly meetings which were eventually hosted over Microsoft TEAMS.

Performance against aims

- Optimise UK supply of GNP at >40tpa, at £30/kg (production cost)
  - 2025 prices communicated to Concretene
- No material selection made by end of Q5
  - Once chosen product specification and TDS can be generated.
  - Hoped to have material ready at product phase by end of Q5 ready to go into full manufacture.
    - H15, 16 and 17 still in R&D/Pilot phase.

Appendix 3 - 2nd level plan

Annex 4

PROJECT PLAN & MILESTONE REGISTER

PROJECT TITLE: GraphEnhance

INNOVATE UK FILE REFERENCE: 10080584

Date: 17 Dec 2024

Responsible Authors Craig Dawson/Alan Beck

Circulation:

MO – Innovate UK
All Project Partners

Work Package Description (Repeat for each Work Package)

Work Package *WP1*: **Title** *Project Management*					
Start date: 01/10/2023 Anticipated total worked-days: End date: 30/11/2024 Work Package Leader: Cobmore (Alan Beck)					
Work Package Objectives: • Project Monitoring and Reporting • Budget Management • Risk Management					
Description of work • Organise Quarterly meeting reviews (QM) • Budget and spend reviews submitted for review at QM • Risk reports updated for review at QM					
Equipment and Facilities •					
Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables					
Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
P1	QM1	I	COBMORE	15/01/24	Completed
P2	QM2	I	COBMORE	15/04/24	Completed
P3	QM3	I	COBMORE	07/24	Completed
P4	QM4	I	COBMORE	10/24	TBC
P5	QM5/Project close-out	I	COBMORE	11/24	TBC
Dependencies					
Items which must be available for this Work Package				Responsibility	

• Collaborative partners	COBMORE, TS, WB
Work Packages dependent on this Work Package	Responsibility
• All	COBMORE

Work Package *WP2*: **Title** *Specifications and Requirements*

Start date: 01/10/2023
Anticipated total worked-days:

End date: 31/12/2023

Work Package Leader: COBMORE (Craig Dawson)

Work Package Objectives:

- Definition of technical performance specification and KPIs for GO and GNP
- Definition of business and operational requirements for GO and GNPs
- Specify concrete mix design & baseline testing
- Preparation of GO production facilities
- Preparation of GNP production facilities

Description of work

- Perform literature review to determine specifications for GO and GNP materials and suggested pathways for production.
- Design an appropriate concrete baseline.
- Determine reproducibility of baseline concrete using statistical analysis
- Prepare GNP production facilities
- Prepare GO production facilities
- Prepare Concretene production facilities (COBMORE formulation laboratory)
- Prepare concrete production facilities (COBMORE Concrete facility)

Equipment and Facilities

- COBMORE Concrete materials testing facility
- COBMORE Formulation Laboratory (GEIC)
- Thomas Swan GNP small scale production
- William Blythes Lab reactor and facilities

Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
D1	State-of-Art Report	I	Craig Dawson (COBMORE)	October 23	Completed

D2	C35 concrete with Std Dev <4	I	Craig Dawson (COBMORE)	October 23	Completed
M1	Graphene and performance specifications defined	I	ALL	October 2023	Completed

Dependencies	
Items which must be available for this Work Package	Responsibility
• Concrete Laboratory and staff • Concrete testing and staff • GEIC membership (literature access)	COBMORE
Work Packages dependent on this Work Package	Responsibility
• WP3 • WP4 • WP7	• COBMORE • COBMORE • COBMORE

Work Package *WP3*: **Title** *Lab based trials*

Start date: 01/11/2023
Anticipated total worked-days:

End date: 14/03/24

Work Package Leader: COBMORE (Camille Wright)

Work Package Objectives:

- Small scale GO synthesised to agreed specifications
- Small scale GNP synthesis to agreed specifications
- Concretene characterisation, imaging, micro/macro structure analysis, chemical & physical testing
- Define Graphene Materials Specification and process parameters (DoE#1)
- Formulation development - Shelf stability and system compatibility (GEIC)
- Mortar and Concrete mechanical testing

Description of work

- Make GO to identified specifications (from D1) in terms of purity, particle size and surface chemistry.
- Make GNP to identified specifications (from D1) in terms of purity, particle size and surface chemistry.
- Design, run and analyse outputs using a multivariant, statistical design of experiment approach (DOE#1).
- Down select best performing GO and GNP from DOE#1 for WP5 & WP6.
- Determine best formulation and process parameters
- Gain understanding of interactions of key variables for optimisation within WP4

Equipment and Facilities

- GEIC auto reactor
- GEIC Particle size analysis
- GEIC Scanning Electron Microscope
- GEIC Raman Spectroscope
- GEIC FTIR
- GEIC TGA
- GEIC Rheometer
- GEIC Freeze Dryer
- GEIC Turbiscan
- COBMORE Formulation Laboratory (GEIC)
- COBMORE Concrete materials testing facility

Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
D3	Make and deliver Graphene Oxide for testing	E/I	COBMORE/WB	December 2023	Completed
D4	Make and deliver GNP for testing	I	TS	December 2023	Completed
D5	Report on preferred raw materials for optimisation of Concretene formulations	I	COBMORE	March 2024	Completed
M2	M2 – Stage-gate meeting and report to decide preferred materials specifications for GNP (BSG) and GO (WB) for pilot level scale-up (March 24).	I	ALL	March 2024	Completed

Dependencies

Items which must be available for this Work Package	Responsibility
• GEIC auto reactor • GEIC Particle size analysis • GEIC Scanning Electron Microscope	• COBMORE

• GEIC Raman Spectroscope • GEIC FTIR • GEIC TGA • GEIC Rheometer • GEIC Freeze Dryer • GEIC Turbiscan • COBMORE Formulation Laboratory (GEIC) • COBMORE Concrete materials testing facility	
Work Packages dependent on this Work Package	Responsibility
• WP4 • WP5 • WP6 • WP7	• COBMORE • WB • TS • COBMORE

Work Package *WP4*: **Title** *Formulation Optimisation (DOE#2)*
Start date: 15/03/24 Anticipated total worked-days: End date: 30/07/24 Work Package Leader: COBMORE (Camille Wright)
Work Package Objectives: • Small scale GO synthesised to agreed specifications (i.e. down selected from M2) • Small scale GNP synthesis to agreed specifications (i.e. down selected from M2) • Concretene characterisation, imaging, micro/macro structure analysis, chemical & physical testing • Begin testing implications of pilot scale manufacture of Concretene. • Mortar and Concrete mechanical testing
Description of work • Make GO to identified specifications (from M2) in terms of purity, particle size and surface chemistry. • Make GNP to identified specifications (from M2) in terms of purity, particle size and surface chemistry. • Design, run and analyse outputs using a multivariant, statistical design of experiment approach to optimise GEN2 Concrete product (DOE#2). • Down select materials specifications and formulation for final Concretene GEN2 product. • Determine process parameters
Equipment and Facilities • GEIC auto reactor • GEIC Particle size analysis • GEIC Scanning Electron Microscope • GEIC Raman Spectroscope

- GEIC FTIR
- GEIC TGA
- GEIC Rheometer
- GEIC Freeze Dryer
- GEIC Turbiscan
- COBMORE Formulation Laboratory (GEIC)
- COBMORE Concrete materials testing facility

Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
D6	From M1 plan design of experiment (DoE2) to determine optimisation of GEN2 product (March 24)	I	COBMORE	March 2024	Complete
D7	Make and deliver GO for testing	I	WB	April 2024	Complete
D8	Make and deliver GNP for testing	I	TS	April 2024	Complete
D9	Report: Process and ingredients specifications for GEN2 Concretene product development	I	COBMORE	Sept 2024	Complete (Nov 2024)
M3	M2 – GEN2 Concretene product fully formulated at laboratory scale	I	ALL	Sept 2024	Complete (Nov 2024)

Dependencies

Items which must be available for this Work Package	Responsibility
• GEIC auto reactor • GEIC Particle size analysis • GEIC Scanning Electron Microscope • GEIC Raman Spectroscope • GEIC FTIR • GEIC TGA • GEIC Rheometer • GEIC Freeze Dryer	• COBMORE

• GEIC Turbiscan • COBMORE Formulation Laboratory (GEIC) • COBMORE Concrete materials testing facility • GO Production facility • GNP Production Facility	• WB • TS
Work Packages dependent on this Work Package	Responsibility
• WP7	• COBMORE

Work Package: *WP5*: **Title:** *Materials trials and GO Scale-up*
Start date: 15/03/24 Anticipated total worked-days: End date: 30/07/24 Work Package Leader: William Blyth (WB)
Work Package Objectives: • Small scale GO synthesised to agreed specifications (i.e. down selected from M1) • Pilot scale GO synthesis to agreed specifications (i.e. down selected from M2) • GO characterisation, imaging, micro/macro structure analysis, chemical & physical testing • Understand production implications of pilot scale manufacture of GO.
Description of work • Make GO at lab scale with varying parameters according to agreed specifications. • Make GO to identified specifications (from M2) in terms of purity, particle size and surface chemistry at pilot scale. • Determine process parameters • Understand implications for scale-up to tonne scale • Understand implications for scale up to 100t scale.
Equipment and Facilities

- GO Production
- GO analysis (PSD, ICP-MS)

Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
WB 1	Produce GO at lab scale for WP3 & WP4	I	WB	December 23 & April 2024	Complete
WB 2	Produce GO at pilot scale for WP7	I	WB	July 2024	On schedule
M4	Preferred GO process scaled to Pilot level	I	WB	July 2024	Complete

Dependencies

Items which must be available for this Work Package	Responsibility
• GO Production facility	• WB
Work Packages dependent on this Work Package	**Responsibility**
• WP7	• WB

Work Package: *WP6*: **Title:** *Materials trials and GNP Scale-up*

Start date: 15/03/24 Anticipated total worked-days:

End date: 30/07/24

Work Package Leader: Thomas Swan (TS)

Work Package Objectives:

- Small scale GNP synthesised to agreed specifications (i.e. down selected from M1)
- Pilot scale GNP synthesis to agreed specifications (i.e. down selected from M2)
- GNP characterisation, imaging, micro/macro structure analysis, chemical & physical testing
- Understand production implications of pilot scale manufacture of GNP.

Description of work

- Make GNP at lab scale with varying parameters according to agreed specifications.
- Make GNP to identified specifications (from M2) in terms of purity, particle size and surface chemistry at pilot scale.
- Determine process parameters
- Understand implications for scale-up to 40 tonne/annum scale
-

Equipment and Facilities

- GNP Production (lab scale)
- GNP Production (Pilot Plant)
- GNP analysis

Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
TS1	Produce GNP at lab scale for WP3 & WP4	I	WB	December 23 & April 2024	Complete
TS 2	Produce GNP at pilot scale for WP7	I	WB	July 2024	On schedule
M5	Preferred GNP process scaled to Pilot level	I	WB	July 2024	Complete

Dependencies

Items which must be available for this Work Package	Responsibility
• GNP Production and test facility	• TS
Work Packages dependent on this Work Package	**Responsibility**
• WP7	• TS

Work Package: *WP7*: **Title:** *Pilot/Planning (Concretene)*

Start date: 01/08/24 Anticipated total worked-days:

End date: 14/11/24

Work Package Leader: COBMORE
Work Package Objectives: • Planning for prototype application • GEN 2 Concretene manufacture at pilot scale • Prototype project application • Durability testing • Performance assessment • Understand production implications of pilot scale manufacture of Concretene.
Description of work • Make GNP at pilot scale with varying parameters according to agreed specifications. • Make GNP to identified specifications (from M2) in terms of purity, particle size and surface chemistry at pilot scale. • Determine process parameters • Understand implications for scale-up to 40 tonne/annum scale •
Equipment and Facilities • GNP Production (lab scale) • GNP Production (Pilot Plant) • GNP analysis
Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
D10	Prototype project scoped and agreed	E/I	COBMORE/Arup(E)	September 2024	Partner with Arup and subcon to deliver
D11	Concretene scaled to 10t/annum	I	COBMORE	September 2024	FMX 5 mixer
M5	Prototype project undertaken	I	COBMORE	November 2024	Complete (Dec 2024)

Dependencies

Items which must be available for this Work Package	Responsibility
• Concretene mini-pilot Production (FMX5 mixer and walk in FH capability) • GEIC Particle size analysis • GEIC Scanning Electron Microscope	• COBMORE

• GEIC Raman Spectroscope • GEIC FTIR • GEIC TGA • GEIC Rheometer • GEIC Freeze Dryer • GEIC Turbiscan • COBMORE Formulation Laboratory (GEIC) • COBMORE Concrete materials testing facility • Contractor (subcon)	
Work Packages dependent on this Work Package	Responsibility
N/A	•

Work Package: *WP8*: **Title:** *Communication, dissemination and exploitation*
Start date: 01/10/23 Anticipated total worked-days: End date: 30/11/24 Work Package Leader: COBMORE
Work Package Objectives: • Business Plan including full supply chain assessment • Technoeconomic analysis and cost-benefit analysis of new supply chain • Quality standard recommendations (w/ Arup) • Environment LCA and EPD • FTO and IP protection • Communicate and disseminate relevant information to end users
Description of work • Exploitation plan • Impact of existing and new IP • Communicate and disseminate data on GEN2 product

Equipment and Facilities

-

Summary of Deliverables : Detail the planned external (E) and internal (I) deliverables

Del. Ref	Title	External / Internal (E/I)	Responsibility	Due Date	Comments / Notes
D12	Exploitation plan (inc. dissemination)	I	COBMORE	November 2024	Ongoing
D13	LCA Report	E	COBMORE (AM)	TBC	Arup/TS in progress - est. Q2 25
D14	EPD Report	E	COBMORE (AM)	TBC	Arup/TS in progress - est. Q2 25
D15	FTO Report	E	COBMORE (CD)	May 2024	Complete Mewburn Ellis & Associates
D16	New IP Filing	E	COBMORE (CD)	November 2024	Mewburn Ellis & Associates
D17	Safety Data Sheet for GEN2	E	COBMORE (CD)	November 2024	Complete
D18	Workshop (End User)	I	COBMORE (AM/AB)	TBC	Breedon, CEMEX TBC
D19	Technical Data Sheet	I	COBMORE (CD)	TBC	In progress, est. Q2 25
D20	Attend relevant Industrial Expo	I	COBMORE (TBC)	March 2024 October 2024	UK Concrete Show UK Construction Week, B'ham NEC
D21	AMBS Report. N.American Market	E	AMBS	March 2024	Report delivered

Dependencies

Items which must be available for this Work Package	Responsibility
NA	
Work Packages dependent on this Work Package	**Responsibility**

NA	•

Summary of Milestones

Detail the planned Milestones (add extra rows as necessary)

Ref	Title	Work Package	Responsibility	Due Date	Cost to milestone (£)	Notes
M1	Graphene and performance specifications defined	WP2	COBMORE	10/23		Completed
M2	Down selected preferred graphene materials and processes	WP3	COBMORE	03/24		Completed
M3	Determine GEN2 Concretene formulation	WP4	COBMORE	09/24		Completed
M4	GO made to specification at pilot scale	WP5	William Blythe	07/24		Completed
M5	GNP made to specification at pilot scale	WP6	Thomas Swan	07/24		Completed
M6	Concretene made to specification at pilot scale and concrete prototype pour completed	WP7	COBMORE	11/24		Completed

concretene™
decarbonising concrete

Appendix 4: Risk register
(final Q5 amends highlighted)

GRAPHenhance Risk Register

concretene™

Assessment Stage:	Q5	**Assessment Date:**	17/12/2024	**Version:**	Q5	**Page:**	60 of 76
Author:	Alan Beck	**Date of next review**	n/a	**Designation:**	Project		

Risk	Effect of risk	IL	IS	IR	Mitigation	RL	RS	RR
					Technical (Risk owner: Craig Dawson)			
Concretene does not achieve appropriate metrics for accreditation	Product cannot be specified for commercial application; delay to prototype project	2	6	**12**	**Mitigate:** Further iterative loop of testing and optimisation outside timeframe of GraphEnhance; test for alternative routes to accredited product **Contingency:** Widen scope of supply chain to include other materials and other production methods for lower cost and carbon footprint; begin testing for durability	1	6	**6**
Poor yield of GO **Yield of GNP**	Supplier operating costs will be inflated, with associated increase in sales price to customer COBMORE pushing commercial viability.	2	4	**8**	**Mitigate:** Partners to work together throughout project to develop feedstock materials at the right specification as economically as possible i.e. not 'over-engineered'. Optimise reaction conditions (temperature, addition rate, reactor design) etc based on existing knowhow. GNP production study already demonstrated target cost is achievable. **Contingency:** Investigate recycling of unreacted starting material (e.g. graphite sediment) back into reaction to improve overall conversion, seek alternative raw materials if proving unachievable.	1	4	**4**
Batch-to-batch variability of GO is unacceptable for Concretene formulation	Inconsistent performance of Concretene, resulting in formulation being unsuitable for structural concrete applications.	4	4	**16**	**Mitigate:** Develop a fundamental understanding of the science and chemistry to inform feedstock specification, robust procedures for consistent reaction control. Sampling during reaction progress and definition of corrective steps if measurements fall outside defined margins. **Contingency:** Further processing/purification by COBMORE before admixture synthesis. Possible mixing of batches to reduce variance. Seek alternative material if consistency is not achieved.	1	4	**4**
Specification of GO scale up does not match lab scale for Concretene formulation	Inconsistent performance of Concretene, resulting in formulation being unsuitable for structural concrete applications.	4	4	**16**	**Mitigate:** Develop a fundamental understanding of the science and chemistry to inform feedstock specification, robust procedures for consistent reaction control. Sampling during reaction progress and definition of corrective steps if measurements fall outside defined margins. **Contingency:** Further processing/purification by COBMORE before admixture synthesis. Possible mixing of batches to reduce variance. Seek alternative material if consistency is not achieved.	1	4	**4**
Surfactants remaining on GNP result in air entrainment into Concretene microstructure	Reduction in Concretene density, with reduction in strength and increase in porosity (leading to reduction in structure service life from water/chemical ingress).	4	3	**12**	**Mitigate:** Screening and develop understanding of surfactant systems against compatibility with existing admixture formulation to select best surfactant/mixture of surfactants and trial as part of this project. **Contingency:** Re-evaluate GNP loading into admixture. Consider offsetting reduced GNP loading with increased GO constituent.	1	3	**3**

New formulations are unstable when stored	Separation in storage tank leads to reduced GEC performance.	2	4	**8**	**Mitigate:** Screening of stabilising additives to prevent agglomeration/separation, with possible reversion to previous formulations with demonstrated stability. Carry out a stability study to understand limitations and add new chemistry to extend if required. Target 12 months stability window.	1	4	**4**
Durability testing shows reduced Concretene performance compared to previous studies	Material becomes undesirable for higher risk structures including bridges, tunnels, platforms etc., limiting market impact of technology.	4	4	**16**	**Mitigate:** Iterative formulation refinement based on micro and macro-structural imaging, with modelling of monitoring data from previous demonstrator projects to enable optimisation for long-term performance. Pilot project performance tested to demonstrate durability criteria. **Contingency:** Focus on lower-risk structural applications (ground-bearing slabs, pavements, precast products).	2	4	**8**
Isothermal calorimetry	Addition of Graphene prevents effective use of existing computer modelling software	3	3	**9**	**Mitigate:** Concretene have employed a cement scientist with expertise in use of Isothermal Calorimeter to develop methodology and modify model if necessary. **Contingency:** Use of isothermal calorimeter to understand impact on early reaction kinetics in CEM-I cements. Inclusion of results as output on DOE2 data set.	2	3	**6**
External conditions for industrial pilot	Low temperatures (November) hinder strength development in graphene-enhanced concrete	4	2	**8**	**Mitigate:** Measure performance of low-paste-temperature mixes in laboratory; carefully curate test cubes from Lobslack pour	4	1	**4**
Safety & Environmental (Risk owner: Craig Dawson)								
Formation of highly toxic by-products and waste products during GO synthesis	Waste treatment needed before re-use or recycling of solvent system.	5	2	**10**	**Mitigate:** Optimisation of process conditions to minimise excess oxidising agent that needs quenching. **Contingency:** Train & equip personnel to safely handle & treat waste to minimise risk to human and environmental health and safety. Any accidents or near misses to be reported according to internal procedure and followed up by senior staff.	1	2	**2**
Risk of graphite oxidation reaction (GO synthesis) overheating. Explosion risk on scaleup	Overheating will result in thermodynamic control of reaction, with formation of unwanted by-products, reducing yield.	3	5	**15**	**Mitigate:** Slow addition rate, apply active cooling, maximise heat exchange with surroundings, use blast resistant reactors and shields, specific training for workforce on explosion risk mitigation. **Contingency:** Accidents & near misses to be reported and investigated by senior staff.	1	5	**5**
Occupational health risk from handling nano/2D-materials	Possible physical harm to workforce	4	3	**12**	**Mitigate:** PPE to be utilised for all personnel handling nano/2D-materials outside of secure container. Use of extraction hoods to minimise inhalation risk.	1	3	**3**
Occupational health risk from handling	Possible physical harm to workforce	4	3	**12**	**Mitigate:** PPE to be utilised for all personnel handling strong acids and oxidising agents. COSHH risk assessments to be signed off by senior staff before any changes to reaction conditions can be implemented.	1	3	**3**

strong acids and oxidising agents					**Contingency:** Accidents & near misses to be reported and investigated by senior staff.			
Release of nano/2D-particles into the environment	Possible environmental accumulation/damage. Impact is low to reflect low (<0.1wt%) overall graphene loading in final concrete and biocompatibility of graphene.	2	2	**4**	**Mitigate**: Materials transfer will be in approved sealed containers. Particles will be processed in aqueous solutions where possible to avoid dust creation. Automated process at batching plant. Once concrete has cured, nanoparticles are physically bound to internal structure, eliminating chance of release & allowing concrete recycling like other concretes. Waste products will be disposed of in a controlled manner.	1	2	**2**
Recyclability of GEC at end of structure life unknown	Increased cost at end-of-life for environmentally friendly disposal. Note: end-of-life impact partially offset by extended lifetime vs OPC.	3	3	**9**	**Mitigate**: Nanoparticles are physically bound to internal structure, eliminating chance of release & allowing concrete recycling like other concretes. LCA and EPD to be completed during project. If overall environmental impact is not significantly improved vs existing products, further development actions will be planned, e.g. incorporation of recycled materials as aggregate.	2	3	**6**
Commercial (Risk Owner: Dave Evans)								
Delay to raising post project financing for GO and GNP plant infrastructure scale up	Delay to Concretene commercial scaleup and longer-term reliance on Chinese suppliers or competitor launches rival product first.	4	4	**16**	**Mitigate:** Scale up plan to be developed during this project and recorded in the Exploitation Plan. WB can scale to 50T GO/year without further CAPEX investment, with dialogue required about further scale up costs. Approval process for further investment will be initiated upon project completion. TS will ring-fence R&D budget for further investment if GRAPHenhance project objectives are successfully achieved.	**1**	4	**4**
Concretene patent is not granted.	IP protection is limited.	2	4	**8**	First UK patent pending (GB2115442.2 Patent Title: 'Graphene Enhanced Concrete and Related Materials'), applied for extended worldwide protection currently being processed. Consultation with our patent attorney, Mewburn Ellis, concludes that relevant IP searches show clear Freedom-to Operate and extend our patent portfolio. There is significant know how associated with the technology.	1	4	**4**
UK-based GO syntheses doesn't meet target production costs. GO production not cost competitive with Chinese suppliers.	Increase in Concretene cost, with likely reduction in projected profit margin.	4	3	**12**	Import taxes and shipping costs will be eliminated from the supply chain. The cost of characterisation and further processing of incoming material will also be eliminated if batch-to-batch quality can be assured by suppliers. COBMORE therefore can accept a price up to 20% higher than the current cost of Chinese supply, however these same economics may not apply for other key markets. Technoeconomic analysis during this project will confirm the maximum viable cost for GO and GNP. **Mitigate:** Engaged with additional GO supplier	2	3	**6**
Competitor innovates similar high-strength concrete.	Emergence of competing products would limit the competitive advantage gained by the consortium partners.	3	4	**12**	COBMORE is the only company worldwide to successfully move GEC out of the lab into real world demonstration projects. The completion of manufacturing activities in this project will enable us to capitalise on this first-mover advantage and begin large-scale commercial Concretene deployment on early adopter sites by Q4 of 2025. **Mitigate:** Draft FTO report does not raise any potential issue for use of Concretene for slab applications	2	4	**8**

Assurance case for projects incorporating novel low-carbon concrete mix design is not sufficiently made	Concretene-enhanced concrete does not meet insurance criteria and cannot be underwritten	2	4	**8**	**Mitigate:** Engage with assurers to understand required criteria	1	4	**4**
Environmental Product Declaration & Lifecycle Analysis	As processes for GNP and GO are also in a developmental phase, final EPD/LCA for these materials is unknown.	4	3	**12**	**Mitigate:** Produce EPD and LCA (for prototype) based on known values for current scale(s) of production. **Contingency:** Produce EPD and LCA (for prototype) based on predicted values for current scale(s) of production.	2	3	**6**
					Managerial (Risk owner: Alan Beck)			
The loss of key personnel.	Delay in product development and of loss of knowledge.	3	3	**9**	All data and results will be carefully recorded according to standardised methods, so that knowledge is not lost with personnel turnover and new staff will be able to get up to speed efficiently.	2	3	**6**
Delay to delivery of subcontracted services.	Project delayed; potential extension needed.	2	3	**6**	COBMORE will subcontract material testing to the Graphene Engineering Innovation Centre (GEIC) at the University of Manchester (Tier 1 member and trusted collaborator since 2019). Subcontracted work will be subject to monthly review by the project manager, and payment will be upon achievement of deliverables.	2	3	**6**
Resources not available when needed.	Project delayed; potential extension needed.	2	3	**6**	The delivery team have been allocated to this project for the duration. Fully equipped in-house laboratories have all equipment to complete project activities, GEIC characterisation facilities secure as part of Tier 1 membership.	1	3	**3**

Risk	= the likelihood of the harm being realised	Rating	Key to risk rating:
Hazard	= something with the potential to cause harm	1-6	= Low
IL/RL	Initial/Residual likelihood or probability	7-9	= Medium
IS/RS	Initial/Residual Severity	8 - 12	= Significant / Medium
IR	Initial Risk Rating	15-25	= Unacceptable / High

RR	Residual Risk Rating		

Appendix 5: Finance summary (at 20 Feb 25)

Project costs to date

	Total eligible costs	Eligible costs claimed to date	Percentage of eligible costs claimed to date
COBMORE HOLDINGS LTD (Lead)	£717,608.00	£717,196.71	99.94%
THOMAS SWAN & CO.LIMITED	£156,194.00	£129,517.66	82.92%
WILLIAM BLYTHE LIMITED	£13,048.00	£0.00	0.00%
Totals	£886,850.00	£846,714.37	95.47%

Partner finance details

	Total eligible costs	Funding level	Total grant approved	Remaining grant	Total grant paid in advance	Claim cap	Claim retention
COBMORE HOLDINGS LTD (Lead)	£717,608.00	70.00%	£502,038.11	£287.89	£0.00	90.00%	£0.00
THOMAS SWAN & CO.LIMITED	£156,194.00	60.00%	£77,710.26	£16,005.74	£0.00	90.00%	£0.00
WILLIAM BLYTHE LIMITED	£13,048.00	0.00%	£0.00	£0.00	£0.00	90.00%	£0.00

Appendix 6: Exploitation plan

(Final Q5 amends highlighted)

Partners' capability to develop and exploit the technology
This project strengthens UK graphene manufacturing – graphene nanoplatelets (GNP), graphene oxide (GO) – paving the way for large-scale exploitation of Concretene to address the identified need for low-carbon concrete. Concretene improves on Ordinary Portland Cement (OPC) and in-development graphene-enhanced concretes (GEC): • CO_2-savings of ~20% (achieved through use of less concrete by volume, lower cement-content, reduced level of anti-crack-reinforcement where design codes allow) vs OPC. • Graphene is dispersed in an aqueous solution which minimises disruption to existing ready-mix industry plant and health and safety procedures. GNP materials specification developed: synthesis optimised (target \>95%-yield), including selection/development of a suitable surface-agent to balance exfoliation efficiency with potential surface agent impacts on the stability/performance of GNP dispersion in Concretene. Scaled-up to 60L batch size. GO materials specification developed: manufacturing piloted (500kg batch reactors) using an adapted-Hummer's method (modified sequence, addition-rate) and standardised conditions to deliver improved batch-to-batch consistency vs existing producers (0.5-2% variance in sp2/sp3-carbon speciation, <0.1% variance sulfur-species-content), enabling greater consistency in Concretene's chemical structure and performance, with best-practice waste-management procedures (on-site waste-treatment plant) to limit pollution vs existing producers. Both materials iteratively tested for compatibility with Concretene. This further develops and then applies existing technologies (GNP/GO synthesis) to a new area (high-performance GEC). A UK patent (GB2115442.2) is published-pending, protecting Concretene's unique GO/GNP dispersion-method. Project partner Thomas Swan's (TS) high-throughput GNP-synthesis is protected in WO2014/140324 – owned by Black Swan Graphene (BSG), TS have full access. Project partner William Blythe's (WB) modified-Hummer's GO-synthesis is protected as company knowhow. Patent attorney Mewburn Ellis confirms freedom-to-operate in preferred early exploitation territories, including for UK market. Outputs: 1. \>40,000kg/year GNP production-capacity, using surface-agents with no detrimental impact on Concretene stability 2. Validated GO, with batch-to-batch variability 0.5-2%, unlocking negotiations for a post-project commercial-supply agreement (WB/Cobmore) for up to 83,000kg/year by 2030. 3. Set of quality-standard specifications for graphene (GNP and GO) manufacturing towards use in Concretene formulations. 4. Validated Concretene formulation with total graphene loading of 3-6% 5. Prototype demonstration, validated against standard durability testing (ATSM_C642/C1293/C452/C1138) 6. Environmental LCA and Environmental Product Declarations for graphene materials and Concretene end product

These outputs enable the Concretene-formulation to be finalised, enabling application for necessary-accreditations (CE/BBA) for full-scale commercialisation using the graphene supply-chains established in this project.

Concretene remains the only known graphene-enhanced admixture for concrete that has been deployed in several pilot-scale structural applications.

However, the low maturity of UK-based manufacturing and supply chains for nano/2D-materials are major barriers to innovation and adoption. The main motivation for the project is to strengthen UK nano/2D-material production capability, specifically GO and GNP.

Concretene is an innovative solution to the urgent global need for concrete decarbonisation.

To finalise and standardise the Concretene formulation (a prerequisite to applying for accreditation), the following technical challenges relating to material manufacturing remain:

1. Tailoring GNP manufacturing to preserve the dispersive interactions between GO and GNP-particles which prevent GNP-agglomeration in Concretene formulations.
2. Validating a standardised, UK supply of GO in Concretene's formulation as an alternative to offshore supply chain. Batch-to-batch variability in previously supplied GO resulted in inconsistencies in Concretene's chemical structure and performance in modified concretes.

Addressing these challenges using UK-based manufacturers will additionally solve Concretene's business need for a low-carbon, resilient supply chain, immune to geopolitical disturbances/price-shocks, and scalable to future demand.

UK chemical/material manufacturers are unwilling to invest in this market opportunity without public funding due to technical and commercial risk.

Similar Innovations:

Innovations by the global cement industry include extensive use of secondary supplementary cementitious materials (SCM) such as ground granulated blast furnace slag and pulverised fly ash. These are by-products of thermal steel production and coal-fired power generation. The decline of these processes in the UK, Europe and North America necessitates use of imported SCM, which is unsustainable.

Although alternative cement systems are available e.g. alkali-activated cements, significant industry adoption has been challenging due to cost and disruption to existing processes and plant meaning adoption is unlikely to occur in the next 5 years, although legislation has recently been modified to allow for greater use of SCM.

Academic literature suggested that Concretene should be complimentary to these low-carbon SCM systems with similar uplifts to OPC systems reported. This was subsequently observed in GraphEnhance (see Appendix 2.9).

Other companies are developing GEC products (e.g. Versarien and First Graphene). These companies are often limited to the use of their own proprietary materials. The general approaches used are described in more detail below. As an independent developer of additive solution technologies, Concretene can specify and select the most suitable graphene materials and is not limited in this way.

Work already done:

Thomas Swan is the exclusive producer of GNP for Black Swan Graphene, which currently supplies Cobmore. TS/BSG have already established pilot-scale GNP-manufacturing in the UK.

William Blythe commissioned pilot-scale infrastructure to manufacture GO in 500kg batches.

This project focused on further developing existing capability (GO/GNP manufacturing) to unlock large-scale exploitation potential of Concretene.

Concretene mobilised a staff of 20 to expedite the development of formulations for GEN2 admixtures.

Concretene completed a state-of-art review of current academic literature to inform development of specifications for GNP and GO specifically for GraphEnhance.

Thomas Swan developed laboratory-scale processes to include surface agents which are complimentary to both graphene and cementitious systems.

William Blythe supplied materials at various levels of purity to determine which is the best-performing.

Concretene completed a multivariant statistical design-of-experiment (DoE 1)to determine preferred specifications for GNP, GO and preferred processing parameters for Concretene production.

Preferred materials and processes were downselected for DoE 2 to further optimise the formulation for performance enhancements.

DoE 2 was completed, further downselecting graphene materials and processing parameters for formulations to be chosen for CEM III industrial pilot.

Partners Willmott Dixon, Breedon and Civic Engineers were selected for industrial pilot pour at Lobslack Seed Distribution Centre, Delamere Forest, scheduled w/c 18 Nov (delayed to w/c 2 Dec).

After an initial operational trial ($2m^3$ pour, Wed 27 Nov) with Breedon and Willmott Dixon, the latter cancelled the main slab pour ($52m^3$) on the basis of unacceptable risk due to a perceived lack of effective curing.

Cube results from this initial trial showed uplifts in compressive strength >20% in both internal and external testing.

As a result of the main pour being cancelled, the Concretene team sought and acquired a new site on which to trial our formulation. The trial (~50m3) took place at Clough Cottage Farm nr. Congleton in Cheshire between 10 and 12 Dec. Here, the 3-day results showed comparable strength uplifts >20%.

Explain the roles of each of the consortium members highlighting the necessary skills and experience

Partners and their roles/resources are summarised below.

Cobmore Holdings Ltd is a new company founded to exploit Concretene. Led by CEO Mike Harrison, the company has secured more than £6m in VC funding through LocalGlobe and Molten Ventures, plus ~£2m in Innovate UK grants to scale and commercialise its graphene-enhanced concrete admixture.

William Blythe has a multi-million turnover of speciality-chemicals (£45M in 2021), primarily flame-retardants and inorganic-salts, and is emerging as the UK's first large-scale GO manufacturer.

Thomas Swan is a multinational performance-chemicals manufacturer, and global-leader in graphene/GNP manufacturing. TS is the exclusive manufacturer of GNPs for Canadian partner-company Black Swan Graphene.

Resources/equipment/facilities:

All necessary equipment is owned by, or can be accessed by, consortium members:

TS GNP production equipment: on-site development-lab, characterisation equipment, reaction-vessels, homogenizers, filtration/washing/centrifuge, dryers, safety/fume-hoods.

WB GO production equipment: heat/corrosion-resistant 500kg-batch-reactors, mixers/stirrers, cooling/chillers, filtration/washing/centrifuge, dryers, safety/fume-hoods and waste-management plant.

Cobmore: Concretene material-development and characterisation labs. Further characterisation equipment is also accessed through a Tier 1 membership of the Graphene Engineering Innovation Centre (GEIC) at The University of Manchester.

External parties/Sub-contractors:

GEIC (world-leading graphene R&D Centre) will undertake analytical services (£52,000). This subcontract is the best value-for-money option to access characterisation/analysis equipment not-available at COBMORE (e.g. Scanning-Electron-Microscope).

All partners have equality, diversity and inclusion policies to ensure issues arising are navigated appropriately. Although the project team represents a diversity of genders and backgrounds, efforts will be made to eliminate racial-bias and sexism, and attract, retain and develop (via reskilling) female and minority-group talent within the consortium during and beyond the project.

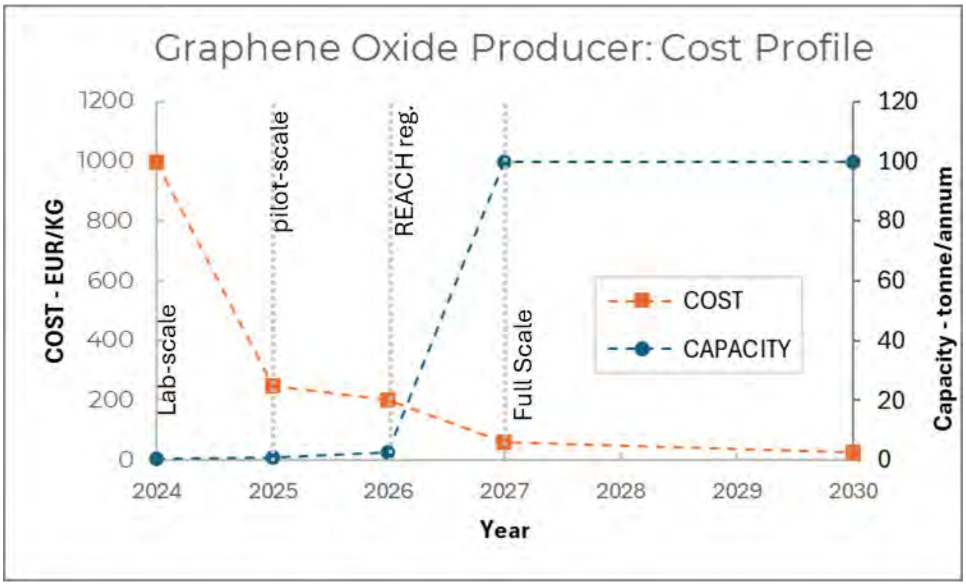
The market opportunity

Summary of Expected Deliverables From Project
Market-position and customers: This project paves the way for establishing large-scale UK-based GNP manufacturing by Thomas Swan. In Q4 2022, William Blythe commissioned a GO-dispersion pilot facility (500kg reactors) and started manufacturing for filtration and polymer-additive applications. As the UK leader in GO production, WB uses this project to extend this leading position by determining product specifications for a new customer (COBMORE), enabling entry to the GEC market. This project will finalise and standardise the Concretene formulation using GO/GNP sourced from WB/TS, to enable post-project accreditation (CE/BBA/BS EN934A), to establish full-scale Concretene supply. The main target customer for the GNP/GO from TS/WB will be Cobmore: TS produced GNPs in a patented high-throughput process using surface agents validated to preserve Concretene's dispersive interactions between GO and GNP particles, at a target sales price of £39/kg (30% gross margin), matching the current-cost of COBMORE's GNP-supply whilst offering a uniquely tailored product. With no other viable UK-based GO supplier, WB's value-proposition to Cobmore is scalable, standardised supply (0.5-2% batch-to-batch-variance). Exact sales price and volume (not currently disclosed due to confidentiality of WB as a public company) will be agreed in a post-project commercial supply agreement. Concretene's initial customers are construction contractors and pre-cast concrete manufacturers (e.g. Roger Bullivant) targeting the wider construction sector. The value proposition for construction contractors is ~price parity with OPC, with carbon-savings helping to meet embodied carbon targets. For pre-cast manufacturers, the major value-add is reduced curing-time, enabling higher throughput of pre-cast structures.

Commercial Opportunity for Each Deliverable
1. **The market niche for each outcome** Route-to-market and increased revenues: TS/BSG and WB will supply GNP (332,800kg/year by 2030) and GO (up to 83,200kg/year by 2030, pending commercial-supply-agreement*) to Cobmore. Cobmore will exploit Concretene by direct sales to contractors and pre-cast manufacturers. Concretene is a drop-in to existing batching plants. Arup (equity partner in Cobmore, presence in >70 countries), will support adoption into building standards/codes in key-markets). Cumulative 5-year revenues - Cobmore: £173M; TS: £28.8M; WB: not disclosed. For the partners, short-term growth be through establishing/further developing large-scale UK GO/GNP manufacturing-capacity by 2025 (TS in Consett, WB in Accrington).

Project outputs are protected via extension of existing patent portfolios. Cobmore and WB own their own results, and TS will retain exploitation/use-rights to IP they generate.

(*calculation of GO price v scale to form basis of post-project negotiation on commercial supply)



	DATE	CAPACITY	COST
LAB-SCALE	2024	0.45	1000
PILOT SCALE	2025	1	250
PILOT SCALE REACH	2026	2.5	200
FULL SCALE	2027	100	60
+EFFICIENCIES	2030	100	25

2. The predicted value and growth in the selected market niche

Project Output 1, a scalable GNP production capacity, targets the emerging global GNP market, valued at £63.2m in 2022 with a growth forecast of 37.4% CAGR (2023-2029). [2]

Project Output 2, a validated future supply of GO dispersion, will target the nascent global GO market, worth £104m in 2022. This is a rapid-growth market (32% CAGR 2022-2033), with forecast value of £2,151m by 2033 [1]. The solution/dispersion-based segment dominates (over powder-based), with 32.6% CAGR.

The main customer for Outputs 1 and 2 will be Cobmore, for downstream processing into Concretene. As a viable replacement for ~95% of today's structural concretes (cost-competitive with OPC), Concretene targets a leading position in the global concrete market, valued at £355bn in 2020, with 4.5% CAGR_2021-2030 [3].

Secondary markets for Outputs 1(GNP) and 2(GO) will be energy-storage, composites, conductive-inks, filters/membranes etc., where customers will include OEMs and research performers. These applications represent a combined market-opportunity worth £492m (2020), with 19% CAGR_2020-2025 [4].

[1]Graphene-Oxide_Market_Outlook_2022-2033(Researchnester.com)

[2]Graphene Nanoplatelets Market 2023-2029(GlobeNewswire.com)

[3]Ready-mix_Concrete_Market_Analysis_and_Industry_Forecast_2020-2030(AlliedMarketResearch.com)

[4]Graphene-Market-by-Type-Global-Forecaset-to-2025(MarketsandMarkets.com)

3. The existing or emerging competitive offerings

Other companies are developing GEC products (e.g. Versarien and First Graphene). These companies are often limited to the use of their own proprietary materials. These GEC developers use the following general approaches to obtain GEC additives:

- P2P - GNP are generally produced within a liquid exfoliation process. Powder to powder dispersion with cement therefore requires energy input to dry the GNP before dispersion. This process also leads to agglomeration of the discrete graphene particles, limiting dispersion in the final cement matrix.
- Aqueous dispersion: Use of surfactants to suspend GNP in aqueous solutions. The use of surfactants can result in excess air-entrainment. This becomes a limiting-factor for GNP-loading and strength-enhancement. This approach also has limitations around the level of graphene that is suspended meaning that large volumes of water are required for application in concrete.

Concretene uses graphene oxide as a dispersing agent for the hydrophobic GNP. This allows a much higher concentration of graphene materials to be dispersed in the water without the need for further addition of surfactants.

4. The means by which IPR will be protected

The patent application for Concretene processing and formulation composition has been submitted and trademark secured. A further patent may be required as a result of the formulation redevelopment.

A report was commissioned with Mewburn Ellis & Associates in the third quarter of the project (by end of September 2024), to ensure freedom-to-operate for UK and related markets. This report was delivered in November.

The potential impact

Summary of wider benefits from the Project for those outside the consortium
Economic: Benefits to Concretene customers: Saving on construction project delivery vs using OPC. We estimate use of Concretene will equate to 15-20% of concrete costs, with improved performance characteristics (~20% addition to compressive strength allowing for ~10% reduction in cement content) and greater durability (TBC to be tested during project, indicative >70%) leading to extended lifecycle of assets, offering savings on project cost and CO2 emissions, application dependent. Benefits to the supply chain/wider industry/UK economy: Deployment of Concretene by COBMORE (~23 million litres by 2030) will propagate economic growth throughout global supply chains, with downstream benefit for cement manufacturers, construction companies, design engineers, government contractors etc. State and privately funded capital transport/construction projects could be completed sooner using Concretene at reduced cost, leading to faster ROI and increased willingness to invest in subsequent projects. Increased demand for feedstock chemicals ($NaNO_3$, H_2O_2 etc) that are already manufactured in the UK, boosting UK chemical sector growth. Production standardisation, scale-up, and potential longer-term cost-reduction, of graphene in the UK will enable import substitution and benefit other strategically important UK industries that are the focus of close-to-market graphene innovations (e.g. consumer electronics - CAGR 4.6%, battery manufacturing - CAGR 15.8%), as well as creating an opportunity for export to worldwide markets. Whole system approach for sustainability trade-offs: There is a trade-off to be made between curing time, and embodied-carbon reduction, which are related inversely by the cement-to-water ratio used in the cement formulation alongside the Concretene admixture. This will be evaluated on an application-by-application basis, depending on user priorities. This project will complete an environmental LCA – to be undertaken by a specialist consultancy as the formulation nears completion, project Q3/4 - to further our understanding of such trade-offs and related parameters. LCA/EPD is still pending. **Environmental** The large-scale deployment of Concretene will reduce the carbon footprint of concrete use across the UK, in line with the carbon reduction strategy. By 2030, Cobmore will deploy ~23 million litres of Concretene through direct contracting alone, mitigating 1.1m tonnes CO_2e, equivalent to 17,000 petrol cars driven for one year. The substitution of 923T of GO Imports from China, based on a shipping carbon footprint of 6.14gCO_2e/km per T of material, and a shipping distance between the UK (Thamesport) and China (Port of Shanghai) of 22,000km, will mitigate approximately 125T of CO_2e in transport emissions by 2030.

Government Priorities/Regional Impacts:

Supporting materials manufacturing in Northern-England (TS in County Durham, WB in Lancashire, Cobmore plans for future manufacturing facility in Atom Valley Advanced Manufacturing Hub, Greater Manchester) by pioneering the use of graphene-enhanced technologies, in line with the government's 'Levelling up', and 'Northern Powerhouse' agendas and the National Materials Innovation Strategy Framework.

Developing an enabling technology for reducing the embodied-carbon in future transport infrastructure and buildings, in line with government priorities described in HC-643_Building-to-net-zero, Sept-2022.

Social:

Creation of new jobs at COBMORE (130 jobs), TS (25 jobs) and WB (4 jobs) over 5 years post-project with further multipliers across UK industry following the project (plant engineering, low-carbon construction etc). These will mainly be skilled jobs in a high-value industry.

Negative Societal/Economical/Environmental Impacts:

The potential negative environmental- and social-health impacts of onshoring Cobmore’s GO supply (process energy, discharge of wastewater, workforce exposure to strong acids etc.) have been considered, but the overall environmental/social health impacts of this will be mitigated by well-enforced UK policies on the classification/storage/transportation/treatment and disposal of Hazardous Wastes, and COSHH/REACH/HSE policies to protect the workforce. The UK environment therefore provides greater environmental/health and safety protection than the equivalent legislations in APAC/China, and TS and WB uphold the highest standards of health and environmental safety practices (e.g. WB top-tier COMAH site status).

The potential negative impact of lost import-taxes on imported graphene materials (\>920T of import substitution by 2030), will be more-than compensated by revenue generation in the UK supply chain for graphene materials (£48m revenue by 2030), which can be reinvested in further capacity growth).

Business Plan

Cobmore Holdings Ltd (formerly NERD) was established in 2022 following the successful development of patentable technologies for aqueous dispersion of graphene nanoplatelets.

Concretene is the first of our application specific products, developed to enhance the properties of concrete and the associated embodied carbon of construction projects. Our partnership with The University of Manchester (UoM) embeds Cobmore within the UoM nanomaterial knowledge hub, globally renowned for the development of graphene.

Cobmore has successfully partnered with Arup and Black Swan Graphene and is actively progressing global supply chain partnerships. Timely delivery of nanotechnology at global scale to achieve collective net-zero ambitions requires partnership with manufacturing and specifying organisations of sufficient capacity.

Arup is advising Concretene on the best route to market from an accreditation point of view. It has identified the easiest route to market as qualification to harmonised European standard – Admixtures for concrete, mortar and grout (BS EN934).

Addressable UK market for Concretene

Arup reviewed the concrete market and the addressable size of the UK market, creating a metric for the global opportunity. Global concrete production in 2020 was circa 10 billion m^3, of which the UK consumption is estimated to be 3.5 million m^3/month, circa 42 million m^3 annually.

Concretene will be manufactured as an admixture, engineered to operate effectively with the other market-leading concrete performance products. Data from the Competition and Markets Authority illustrates circa 80% of the market is supplied by five primary organisations. This simplifies the resources required for entry to market, as relationships with the major market operators, supported by compatibility testing, will ensure industry-wide adoption. Admixtures are readily used in the industry, while construction codes and standards define the use and performance requirements for concrete production. Concretene is fully compliant with these requirements, product performance assurance being the governing factor to industry adoption.

Arup reviewed the barriers to Concretene adoption and graded each sector either red, amber or green relative to complexity or barrier to use. Their assessment confirms that buildings, civils and precast industries that constitute over 75% of total consumption are readily addressable. Technical Infrastructure and Nuclear will have a longer approval model that will be driven by data from conventional applications. BS EN 934 (admixtures for concrete, mortar and grout) and CE/UKCA marking will be progressively achieved through a 24-month assurance process.

UK cement/cement replacement materials consumption

The concrete market remains stable in the UK with consumption of cement and cement replacement materials (CRM) recovering quickly post-pandemic.

The UK's total annual consumption of cement is 11.6 to 12.4m tonnes. These figures imply average cement contents of ~250-325kg/m^3.

Annual consumption of cement replacement materials (CRM) in the UK – mainly ground granulated blast furnace slag (GGBS), fly ashes (FA) and other concrete additions - is between 2.8 and 3.6m tonnes. Arup estimates that around 50% of the CRM used in the production of concrete in the United Kingdom comes from imports. Typically, CRM amount to ~20% of the overall binder used in the concrete mix.

	2026	2027	2028	2029	2030	Tota
CONCRETENE sales (L)	400,000	1,466,667	3,866,667	6,933,333	10,400,000	23,066,667
revenue (£)	3,000,000	11,000,000	29,000,000	52,000,000	78,000,000	173,000,000
GO supply (kg)	3,200	11,733	30,933	55,467	83,200	184,533
GNP supply (kg)	12,800	46,933	123,733	221,867	332,800	738,133
TS revenue (£)	499,200	1,830,400	4,825,600	8,652,800	12,979,200	28,787,200

Concretene market opportunity

UK market

It is anticipated that Concretene will represent between 4-6% of concrete costs, equating to a whole market opportunity of £300**m/pa** for the UK.

Asset owners in all sectors, constructors and concrete suppliers are committed to reducing embedded carbon in construction and view the carbon reducing properties of Concretene as a major step forward for the industry. We anticipate uptake will be swift, the annual market value growing progressively as addressable sector assurance processes achieve compliance. The readily addressable market in sectors that have the lowest barrier to entry represents 20% of the total market, growing to a potential 75% as the market matures.

Dissemination Activities

We will continue to target trade, local and national press across themes of construction, technology, environment (Concretene has already gained favourable coverage in The Times, BBC news, New Civil Engineer, Construction Enquirer and more). We will use Concretene's social media and website, alongside the channels of our strategic partners, to provide regular updates on progress.

Contact

alan.beck@concretene.co.uk

Graphene Engineering Innovation Centre
The University of Manchester
Sackville Street
Manchester
M1 3BB

www.concretene.co.uk

concretene™