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# APPLICATION OF CONCRETE ENCASED ECOBRICK BLOCKS IN THE UK'S CONSTRUCTION INDUSTRY

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## ABSTRACT

The construction industry within the UK is at the forefront of new and alternative materials, which aid in efficient, sustainable and environmental-friendly construction projects. The concept of filling a single use plastic bottle with plastic waste and encasing it within a concrete surround, producing a composite block meets all three objectives. Due to the lack of ecobrick research within the UK, it became the catalyst for researching the concrete encased ecobrick block. At 7 day compressive testing the composite blocks were all weaker than the control samples and at 28 days the results were mixed. In comparison to a global study (Oman) the composite blocks were all greater in compressive strength. In conclusion, the composite blocks were found to be adequate for non-load bearing structural elements within the UK's construction industry.

**KEYWORDS:** sustainable construction, plastic bottle, plastic waste, ecobrick, composite blocks.

# 1. INTRODUCTION

## 1.1. Ecobricks

Ecobricks are a fairly new concept in the field of civil engineering, with existing uses in walls (using timber frames or mortar) and garden furniture. The ecobrick reduces plastic waste, pollution and provides shelter in areas of poverty (Sebambo, 2015), while being instant, simple and cost-effective.

An ecobrick consists of a plastic bottle and filled with plastic waste used as building blocks (Ecobricks, 2013 para.2). The first documented ecobrick concept was sand filled by Andreas Froese in 2000 to utilise discarded PET bottles (Zero Waste Hero, 2019). In 2003, plastic-filled PET bottles were introduced in Ometepe by Alvaro Molina (LeFevre, 2019) and in Guatemala by Susana Heisse (Upcycle Santa FE, 2020).

The ecobrick is an excellent yet simple method for plastic waste disposal and combined with its potential uses in construction, can aid in a sustainable future which might be the UK's saviour in reducing non-recyclable plastic waste while inviting a fairly simple and relatively new construction method. Combing ecobricks encased within a concrete block dramatically reduces the amount of plastic waste sent to landfill while reducing concrete requirements, subsequently reducing the strain on natural materials.

## 1.2. Current Ecobrick Research

Dieleman and Maier (2018) offer a historic insight regarding ecobrick longevity, which is vital for future ecobrick uses. Preventing issues from degradation, the ecobricks' deterioration can be reduced. Dieleman and Maier did not observe gases within the ecobricks, and missed the opportunity to assess gas type, pressures and explosiveness, which all require further investigation. Further missed was the opportunity to analyse contamination issues from plastic degradation and chemical leaching.

Interestingly, Antico et al. (2017) used a single filler concept to aid in future reuse and found the compressive strength increased with the bottle size. With plastic taking over a hundred years to degrade, the single filler option offers a way to store material for future reuse or recycling. This combined with the ecoblock concept provides a simple method for material retrieval and demolition. Oyinlola et al. (2018) focused on the project team to deliver affordable housing, although sand and water-filled PET bottles were encased in concrete and tested. Plastic filled bottles would have benefited the study from an environmental perspective. The lack of test results in the Oyinlola et al. research offered little comparison to this study.

Goyal and Manisha (2016) claimed ecobricks were considerably stronger than concrete in one case study; however, there was no evidence to support this. It was found by Taaffe et al. (2014) the individual strength of an ecobrick was on par with concrete cubes. It can be argued that more research is required for more supporting evidence. Importantly raised by Goyal and Manisha, the decomposability of the ecobrick. If the current global plastic amount is not reduced and plastic waste continues to rise, there is no balance between plastic reduction and the environment. Government incentives should be used to reduce the amount of plastic waste through ecobricks. If ecobricks cannot be used in construction, at least the plastic waste is contained from polluting. Hall (2020) mentioned that the plastic issue has not gone when using ecobricks yet, delaying the plastic waste issue, this in some ways can be argued as right. The ecobrick contains the plastic waste until it can decompose or be recycled. The decomposability duration may encourage the ecobrick to be a plastic waste storage method until new recycling methods are found, similar to the Antico et al. method.

Important themes emerged from the existing research; ecobricks are predominantly used to reduce the plastic waste impact, which can be argued as the only purpose. It was found ecobricks provide poverty areas with home; this is where more testing is required regarding potential pollutants and harmful effects on the environment. It became apparent that if ecobricks were used in the right way they could be reused again and again following a delicate demolition process; this is an ideal sustainable material. Income generation was also found to be in some research and benefits poverty areas. The majority of the existing research was found to be based outside of the UK in poverty areas with poor waste management; this can be argued as the driver of the ecobrick; this study offers to fill the gap in the UK. The lack of research utilising plastic waste-filled ecobricks or composite concrete encased plastic filled ecobrick blocks in the UK was the catalyst to this research project. No studies are present in the UK testing plastic ecobricks or composite methods using plastic. Currently, research in the UK surrounds sand and water-filled ecobricks with and without encasement (Oyinlola et al., 2018). The remaining research was found to be global and undertaken in Bangladesh (Muyen, Barna and Hoque, 2016), Oman (Safinia and Alkalbani 2016) and Ireland (Taaffe et al., 2014) to name a few. In their own right each research has its own variable, such as sand filled, not encased, water filled. Therefore, this research was completed to British Standards as the initial benchmark for future studies to base comparisons upon. It was found the type, testing, and purpose within the current research varied, which caused inconsistencies in research comparison. It is important for the environment and the construction industry to be at the forefront of new methods to reduce environmental impacts; whether the method is as simple as a plastic filled bottle or not. More testing and research is required to ensure the ecobrick can be favoured in the construction industry.

## 2. METHODOLOGY

The purpose of this research project is to ascertain whether concrete encased ecobrick blocks could be used as a composite construction material in the UK. This was achieved by undertaking compressive strength testing on both the concrete encased ecobrick blocks and traditional concrete blocks. The traditional concrete blocks were used as control samples to aid in comparative results. Both blocks were created and tested to the latest guidance and standards in the UK to give further clarity in comparison. The quantitative data generated from the testing the concrete encased ecobrick blocks and traditional blocks was in the form of the compressive strength test results. The results from both types of blocks gave way to a primary data analysis between the composite blocks and the traditional concrete blocks. The traditional concrete blocks were utilised as control samples in comparison to the composite blocks to justify the strengths for use in the construction industry. This composite block will be an innovation in terms of construction techniques in the UK.

By determining the potential amount of concrete encased ecobrick blocks generated from non-recyclable plastic waste produced in Wales and potential concrete reduction will further solidify the full potential the composite blocks have to offer. This will be done by firstly calculating how much plastic a 500ml plastic bottle will hold and then analysing the current waste figures to understand the amount of potential ecobricks created. Then, by calculating the amount of concrete saved by encasing the ecobrick the natural material reduction can be quantified. In 2019 the UK produced 73,554 thousand square metres of concrete blocks in the UK (DBEIS, 2020), which shows the importance of the need to reduce concrete.

### 2.1. Design Choices – Design Standards and Guidance

The concrete for both the composite and traditional blocks were designed in accordance British Standards *BS EN 1991-1* (BSI, 2002a), *BS EN 1990* (BSI, 2002b), *BS EN 206* (BSI, 2016), *BS 8500-1* (BSI, 2020) and *BS 8500-2* (BSI, 2019a). All testing was in accordance with *BS EN 12390-1* (BSI, 2012), *BS EN 12390-2* (BSI, 2019b), *BS EN 12390-3* (BSI, 2019c) and *BS EN*

*12390-4* (BSI, 2019d). This ensured all blocks were created and tested to current standards used in the UK's construction industry. All testing was undertaken in the LJMU Laboratories.

### 2.2. Ecobricks

For the results to be comparable to other test data the Lenkiewicz and Webster (2017) ecobrick method was adopted, Fig. 1. This ensured the ecobricks were a uniformed standard throughout, Fig. 2. A 500ml PET bottle size was chosen to allow sufficient concrete cover based on the concrete cube size available. 6 ecobrick samples were required, 3 samples for 7 day testing and 3 samples for 28 day testing.

**Fig. 1. Packing non-recyclable plastic waste into PET bottles.**

**Fig. 2. Uniformed Ecobricks.**

### 2.3. Concrete Encased Ecobricks Blocks

The concrete encased ecobrick blocks consisted of an ecobrick as the inner fill and a concrete surround as the outer cover. It was important for ample covering to the width of the ecobrick to ensure transitional loading through the cube, Fig. 3. In addition the ecobrick required cover in its entirety to prevent photodegradation; to ensure the composite block could be utilised outdoors in the UK.

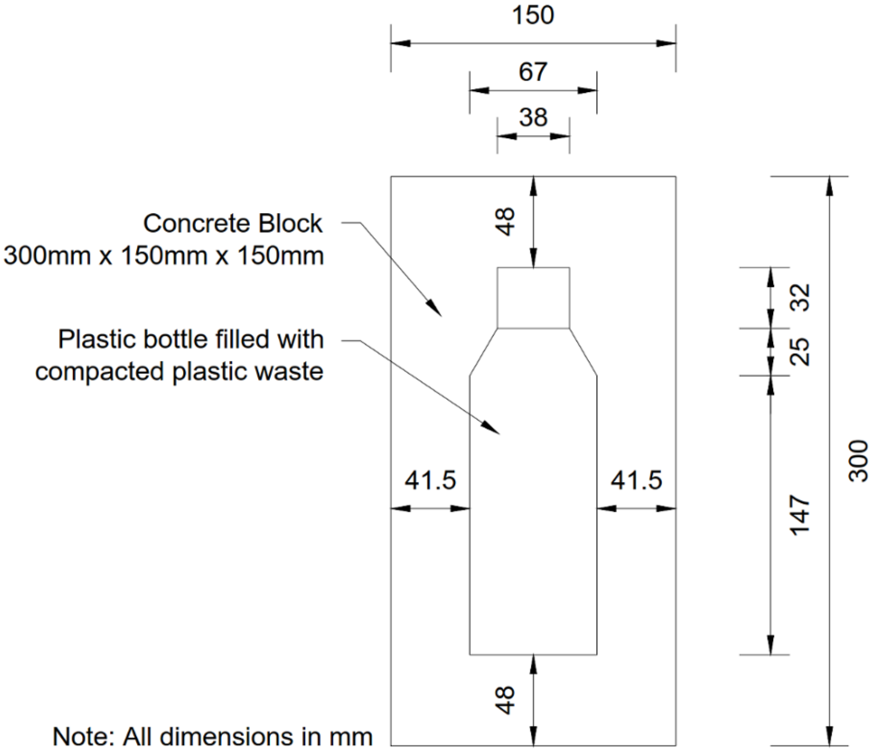


**Fig. 3. Proposed Concrete Encased Ecobrick Design.**

The size of the composite block was 300mm x 150mm x 150mm and 7 samples were required, Fig. 3. The ecobrick was placed centrally in the cube casing, Fig. 4. This was verified by measuring the depth of concrete in the base of the cube and measuring around the ecobrick. The ecobrick was held in position and concrete was placed to *BS EN 12390-2:2019* (BSI, 2019b), see Fig. 5. Table 1 shows the concrete mix design and weighted proportions.

**Fig. 4. Ecobrick placed centrally in concrete cube casing.**

**Fig. 5. Casted Concrete Cubes.**

**Table 1. Concrete Mix Design and Proportions.**

| Mix | Dimensions (mm) | Cement kg/m³ | Course Aggregate (20mm down) kg/m³ | Fine Aggregate kg/m³ | Water/Cement Value |
|---|---|---|---|---|---|
| Traditional Concrete Block | 150x150x300 | 333 | 1000 | 500 | 150 |
| Concrete Encased Ecobrick Block | 150x150x300 | 333 | 1000 | 500 | 150 |

The composite block was manufactured to *BS EN 12390-1:2012* (BSI, 2012) and *BS EN 12390-2:2019* (BSI, 2019b). Compressional testing was undertaken to *BS EN 12390-3:2019* (BSI, 2019c) and *BS EN 12390-4:2019* (BSI, 2019d). The composite blocks cured for 7 days and 28 days, the samples were cured in water baths at room temperature submerged in tape water. Once the sample had cured the sample was weighed and placed within the compression testing machine, Fig. 6. Results were recorded when an initial crack appeared in the composite block and when complete failure was reached.

**Fig. 6. Concrete Cube within Compressive Testing Machine.**

To aid in the life cycle of the composite block it was decided individual composite blocks would be easier for demolition and future reuse. Meaning the blocks could be removed, cleaned of mortar and reused in other projects. Also, breaking individual blocks to retrieve the ecobrick may offer a safer way to prevent damaging said ecobrick.

### 2.4. Traditional Concrete Blocks

Traditional blocks were made to the same concrete specifications, dimensions and standards (BSI, 2012, 2016, 2019a, 2019b and 2020) as the composite blocks, with the only difference being no ecobrick filler and 6 samples were required. The traditional blocks were also tested to the same standards (BSI, 2019c and 2019d) for compressive strengths at 7 and 28 days. The uniformity aided in the comparison of results to the composite blocks and other UK studies.

### 2.5. Global Comparison

The composite block results were compared to a global study; specifically, the Safinia and Alkalbani study. This research was chosen in comparison due to the similar techniques used, although some variations i.e. empty plastic bottles. The Safinia and Alkalbani compressive strength results were compared to the composite block results to add validity to this research globally.

## 3. RESULTS & DISCUSSIONS

### 3.1. Concrete Encased Ecobrick Blocks

The concrete encased ecobrick block sample reference is broken down in Table 2. The composite blocks were tested at 7 and 28 days, Table 3 shows the maximum load and compressive strength results.

**Table 2. Concrete Encased Ecobrick Block Samples – Sample Reference.**

| Sample Reference | Denotation |
|---|---|
| CE 7-1 | CE – Concrete Encased Ecobrick Block Sample<br>7 – 7 Day Testing<br>The last no. (1) denotes sample number |
| CE 7-2 | |
| CE 7-3 | |
| CE 28-1 | CE – Concrete Encased Ecobrick Block Sample<br>28 – 28 Day Testing<br>The last no. (1) denotes sample number |
| CE 28-2 | |
| CE 28-3 | |

The 7 day testing results showed sample CE 7-1 had a higher cracking appearance, yet lower overall maximum load, approximately 22% (70kN) less than the other two samples. The compressive strength was 10.63MPa, which was observed as the lowest result of the initial samples by 22%. Sample CE 7-2 had the lowest crack appearance observed at 140kN. The maximum load and compressive strength of this sample were mid-range although the weight of this sample was the heaviest. Sample CE 7-3 presented a maximum load of 308.2kN and compressive strength of 13.7MPa, the largest of the three samples. This sample weighed the least with a 70 gram difference.

The 28 day testing resulted showed Sample CE 28-1 had the lowest maximum loading of 315kN, lowest compressive strength of 14.00MPa and weighed the least, 14.95kg. The maximum loading of Sample CE 28-2 increased from Sample CE 28-1 by 39%, making it 439.7kN. The compressive strength was recorded at 17.54MPa, a 25% increase over the first sample. Both samples (CE 28-1 and CE 28-2) were observed to have the same initial crack appearing during loading. Sample CE 28-3 had the largest values from all the composite samples. The results were 350kN initial crack appearance, 473.3kN maximum loading and 21.04MPa compressive strength. Both the maximum load and compressive strength increased by 50% from the weakest sample (CE 28-1). Sample CE 28-3 had a mid-range weight (15.05kg) of the three samples. The samples had a minimal weight difference of a 100 grams. Fig. 9 and

Fig. 10 show the initial crack appearance, maximum loading and compressive strength of each sample. Table 3 shows all results and Fig. 7 shows the compressive strength of each sample.

**Table 3. Concrete Encased Ecobrick Block Samples – 7 and 28 Day Results.**

| Sample Reference | Initial Cracking Appearance kN | Maximum Load kN | Compressive Strength MPa | Weight kg |
|---|---|---|---|---|
| CE 7-1 | 200 | 239.20 | 10.63 | 14.99 |
| CE 7-2 | 140 | 301.80 | 13.41 | 15.04 |
| CE 7-3 | 180 | 308.20 | 13.70 | 14.97 |
| CE 28-1 | 200 | 315.00 | 14.00 | 14.95 |
| CE 28-2 | 200 | 439.70 | 17.54 | 15.05 |
| CE 28-3 | 350 | 473.30 | 21.04 | 15.00 |

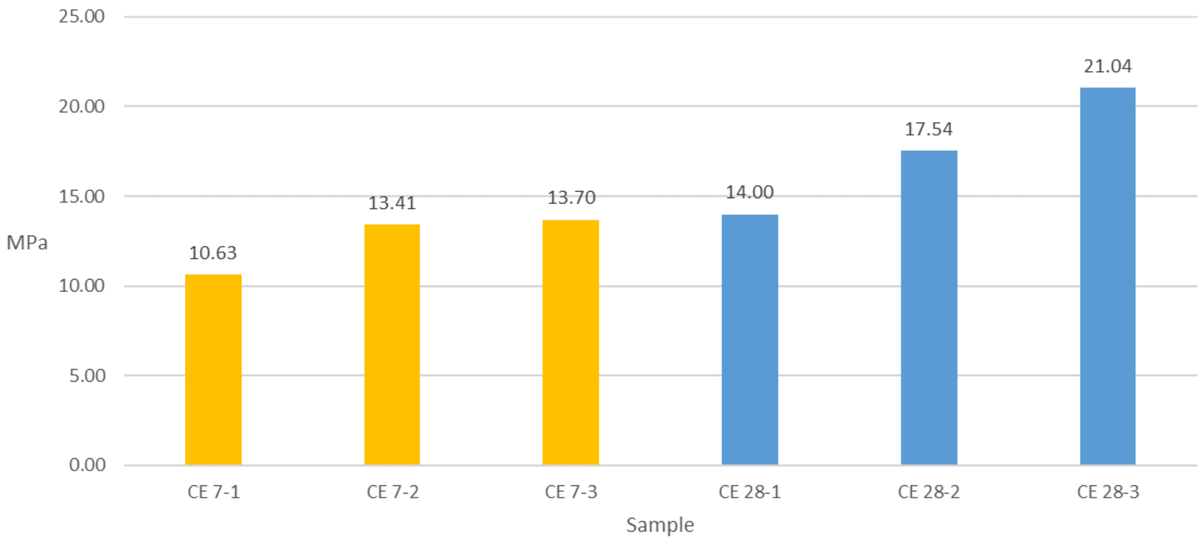


**Fig. 7. Concrete Encased Ecobrick Block Samples – 7 and 28 Day Compressive Strength Results.**

An outlier analysis was conducted on the samples, see Table 4. The Outlier analysis shows sample CE 7-1 lies outside the data set as the lowest sample after 7 days by 2.79MPa. Where sample CE 28-1 after 28 days was the lowest sample by 3.54MPa.

**Table 4. Concrete Encased Ecobrick Block Samples – 7 and 28 Day Outlier Analysis Results.**

| Sample Reference | Compressive Strength MPa | Removing Outlier | New SD |
|---|---|---|---|
| CE 7-1 | 10.63 | - | 0.21 |
| CE 7-2 | 13.41 | 13.41 | |

| | | | |
|---|---|---|---|
| CE 7-3 | 13.70 | 13.70 | |
| Mean Value | 12.58 | | |
| SD | 1.69 | | |
| | | | |
| CE 28-1 | 14.00 | - | 2.47 |
| CE 28-2 | 17.54 | 17.54 | |
| CE 28-3 | 21.04 | 21.04 | |
| Mean Value | 17.53 | | |
| SD | 3.52 | | |
| | | | |

It was identified after 28 days the compressive strength of the three samples gave a range from 14MPa to 21.04MPa. In accordance with Table 5 the compressive strength of each composite block differed over three different concrete strength classes, Sample CE 28-1 was C8/12 (ST2), Sample CE 28-2 was C12/15 (ST3) and Sample CE 28-3 was C16/20 (ST4). Showing a varied range for the usage potential of the composite blocks, it also indicated the samples meet British Standard.

**Table 5. Standardized prescribed concretes and indicative strengths compared to the Concrete Encased Ecobrick Block Samples (BSI, 2020).**

| Standardized prescribed concretes and indicative strengths (BSI, 2020) | | | 28 Day Result Sample from this research |
|---|---|---|---|
| Standardized prescribed concrete | Strength class that may be assumed for structural design | Characteristic compressive cube strength at 28 days that may be assumed for structural design MPa | |
| ST1 | C6/8 | 8 | N/A |
| ST2 | C8/10 | 10 | Sample CE 28-1 |
| ST3 | C12/15 | 15 | Sample CE 28-2 |
| ST4 | C16/20 | 20 | Sample CE 28-3 |
| ST5 | C20/25 | 25 | N/A |

Results show the composite blocks could be used for construction elements requiring lesser loads. It was evident during the analysis to improve this research more compressive testing would have benefited this study to precisely confirm its uses in construction projects. However, the initial testing within this study sets the benchmark for future studies. Additionally weighing the ecobricks would have given scope for a strength to weight ratio as no indication was observed with the composite blocks.

### 3.2. Traditional Concrete Blocks

Traditional concrete block control samples were created and tested to the same parameters as the concrete encased ecobrick blocks, this gave a fair comparison between the data sets. Table 6 shows the sample reference breakdown and Table 7 shows the 7 and 28 day testing results.

**Table 6. Traditional Concrete Block Samples – Sample Reference.**

| Sample Reference | Denotation |
|---|---|
| TC 7-1 | TC – Traditional Concrete Block Sample |
| TC 7-2 | 7 – 7 Day Testing |
| TC 7-3 | The last no. (1) denotes sample number |
| TC 28-1 | TC – Traditional Concrete Block Sample |
| TC 28-2 | 28 – 28 Day Testing |
| TC 28-3 | The last no. (1) denotes sample number |

**Table 7. Traditional Concrete Block Samples – 7 and 28 Day Results.**

| Sample Reference | Initial Cracking Appearance - kN | Maximum Load kN | Compressive Strength MPa | Weight kg |
|---|---|---|---|---|
| TC 7-1 | 377.00 | 377.10 | 16.76 | 15.92 |
| TC 7-2 | 320.00 | 336.10 | 14.94 | 15.96 |
| TC 7-3 | 128.00 | 401.40 | 17.84 | 15.96 |
| | | | | |
| TC 28-1 | 460.00 | 543.80 | 24.17 | 16.07 |
| TC 28-2 | 379.90 | 379.90 | 16.88 | 16.20 |
| TC 28-3 | 514.50 | 514.50 | 22.87 | 16.20 |

An outlier analysis was conducted on the samples, see Table 8. The Outlier analysis shows sample TC 7-2 lies outside the data set as the lowest sample after 7 days by 2.90MPa. Where sample TC 28-2 after 28 days was the lowest sample by 5.99MPa.

**Table 8. Traditional Concrete Block Samples – 7 and 28 Day Results Outlier Analysis Results.**

| Sample Reference | Compressive Strength MPa | Removing Outlier | New SD |
|---|---|---|---|
| TC 7-1 | 16.76 | 16.76 | 0.76 |
| TC 7-2 | 14.94 | - | |
| TC 7-3 | 17.84 | 17.84 | |
| Mean Value | 16.51 | | |
| SD | 1.46 | | |
| | | | |
| TC 28-1 | 24.17 | 24.17 | 3.88 |
| TC 28-2 | 16.88 | - | |
| TC 28-3 | 22.87 | 22.87 | |
| Mean Value | 21.31 | | |
| SD | 3.17 | | |
| | | | |

Sample TC 7-1 was the lightest of the 7 day results at 15.92kg. The initial crack appearance was observed at 377kN, which was the highest of the three samples. The maximum load and compressive strength results were mid-range of the three samples. Sample TC 7-2 recorded the lowest compressive strength sample at 16.76MPa, where the initial cracking was observed at 320kN. Sample TC 7-3 had the highest maximum loading and compressive strength of the 7 day samples. Although the initial cracking appearances was recorded at 128kN, the lowest of the 7 day samples. Sample TC 7-3 also weighed the greatest at 15.96kg.

After 28 days, Sample TC 28-1 had the greatest maximum load and compressive strength of all the traditional concrete blocks. Whilst being the lightest sample at 16.07kg of the three. TC 28-2 was observed to be the weakest of the three samples with 379.9kN maximum loading and 16.88MPa compressive strength. Where the initial crack appearance was observed at 379.9kN, mid-range of the three samples. Sample TC 28-2 also weighed the same as Sample TC 28-3. Sample TC 28-3 was recorded to have the second largest maximum load and compressive strength. The initial crack appearance was also observed at 514.5kN. The maximum loading and compressive strength results at 7 and 28 days are shown in Figs. 12 and 13.

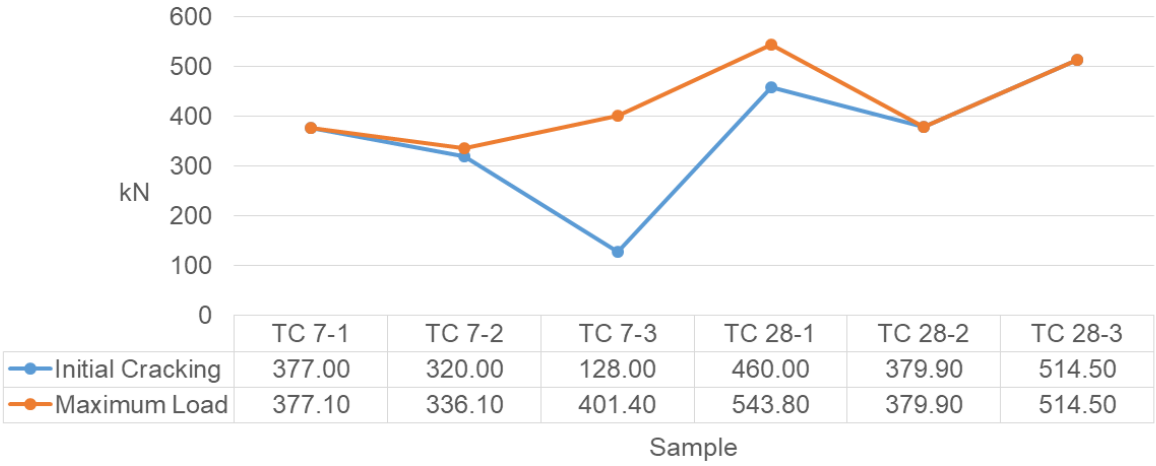


**Fig. 12. Traditional Concrete Block Samples – Initial Cracking Appearance and Maximum Load at 7 and 28 Day Testing.**

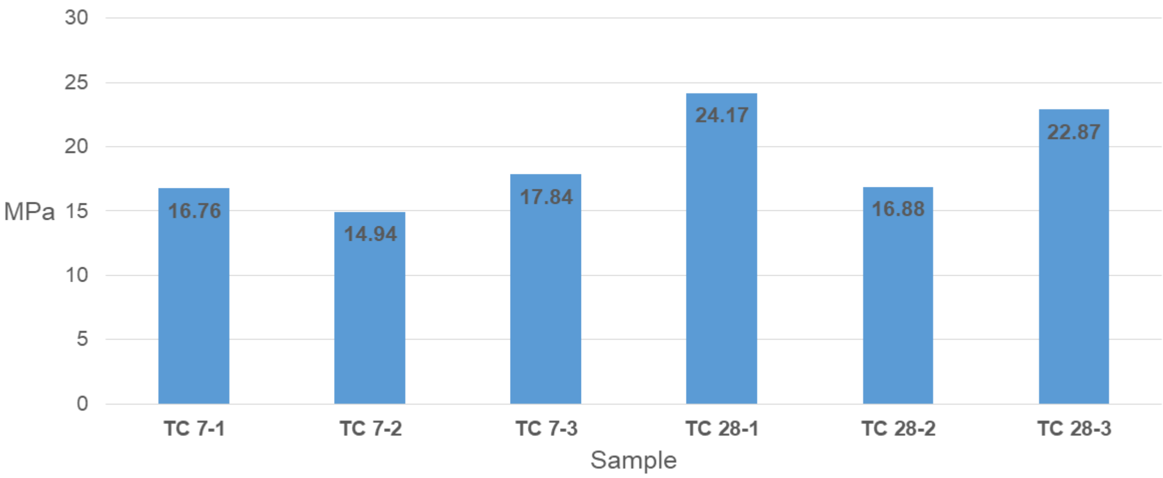


**Fig. 13. Traditional Concrete Block Samples – 7 and 28 Day Compressive Strength Results.**

## 3.3. Comparative Results and Discussion

The initial comparison between the concrete encased ecobrick blocks and the traditional concrete blocks was undertaken with the 7 day results, Table 9.

**Table 9. Concrete Encased Ecobrick Block Samples and Traditional Concrete Block Samples – 7 and 28 Day Results Comparison.**

| Sample Reference | Initial Cracking Appearance kN | Maximum Load kN | Compressive Strength MPa | Weight kg |
|---|---|---|---|---|
| CE 7-1 | 200 | 239.20 | 10.63 | 14.99 |

| | | | | |
|---|---|---|---|---|
| CE 7-2 | 140 | 301.80 | 13.41 | 15.04 |
| CE 7-3 | 180 | 308.20 | 13.70 | 14.97 |
| | | | | |
| TC 7-1 | 377 | 377.10 | 16.76 | 15.92 |
| TC 7-2 | 320 | 336.10 | 14.94 | 15.96 |
| TC 7-3 | 128 | 401.40 | 17.84 | 15.96 |
| | | | | |
| CE 28-1 | 200.00 | 315.00 | 14.00 | 14.95 |
| CE 28-2 | 200.00 | 439.70 | 19.54 | 15.05 |
| CE 28-3 | 350.00 | 473.30 | 21.04 | 15.00 |
| | | | | |
| TC 28-1 | 460.00 | 543.80 | 24.17 | 16.07 |
| TC 28-2 | 379.90 | 379.90 | 16.88 | 16.20 |
| TC 28-3 | 514.50 | 514.50 | 22.87 | 16.20 |

The initial results show the sample weight difference between the composite block and the traditional concrete block were approximately 1kg. This was expected due to the ecobrick fill density being much less than the concrete. The tradition concrete block samples after 7 days were all greater than the composite block samples in both maximum loading and compressive strengths. It was found the difference between the lowest maximum loading samples were 96.60kN or 33%. Where the greater maximum loading samples had a 26% difference or 93.20kN. Both samples sets were nearly 100kN in difference. It was found the compressive strength of the traditional concrete blocks were up to 68% greater than the composite samples. No correlation was found between either data sets regarding increased strength and increased weight. The results show the traditional concrete block samples were heavier and gave greater strength in comparison to the composite blocks. The maximum loading and compressive strength of the strongest composite blocks were still weaker than the lowest strength of the traditional blocks after 7 days. Interestingly the lowest initial crack appearance was observed from the strongest traditional concrete block (TC 7-3) at 128kN. Where the lowest initial crack appearance of the composite blocks was observed at 140kN. The other traditional concrete blocks achieved a greater initial cracking value than the maximum loading values of the composite blocks. Fig. 14 shows the 7 day compressive strength comparative results.

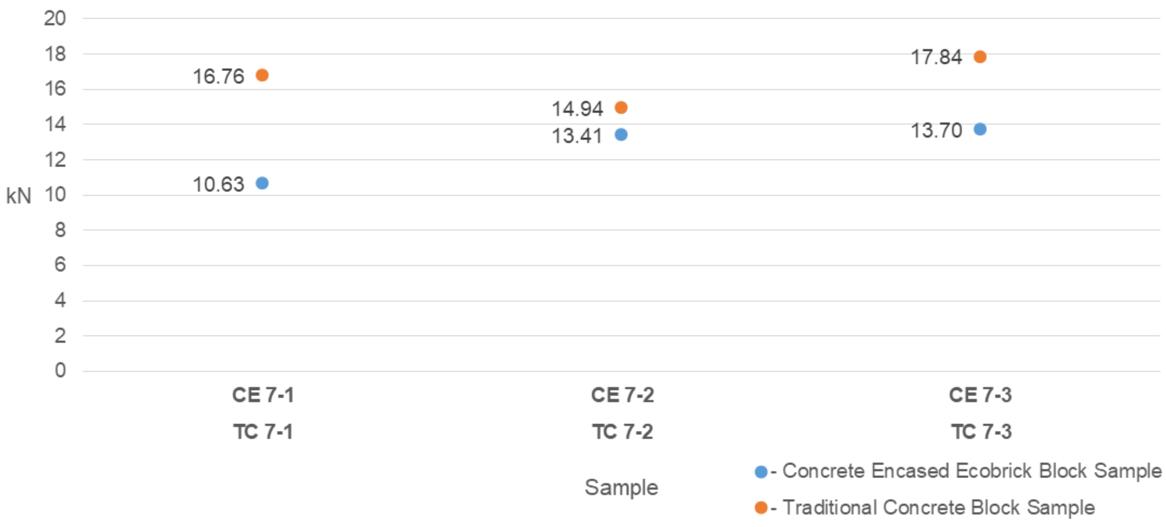


**Fig. 14. Graph 1-7 – Concrete Encased Ecobrick Block Samples and Traditional Concrete Block Samples – 7 Day Compressive Strength Results Comparison.**

4.

The 28 day testing results between the concrete encased ecobrick blocks and the traditional concrete blocks were compared, Table 9. The comparative findings between the composite blocks and the traditional concrete blocks after 28 days show an increase in weight difference. The traditional concrete blocks were approx. 1.25kg heavier than the composite block. No correlation was observed between an increase in weight and an increase in strength. Sample TC 28-2 and TC 28-3 were both the strongest and weakest in the traditional concrete block data. After 28 days two of the traditional concrete blocks (TC 28-1 and TC 28-3) gave the greatest maximum loading and compressive strength values, Table 8. Sample TC 28-2 displayed lesser maximum loading and compressive strengths than two of the composite blocks (CE 28-2 and CE 28-3); this was similar to the traditional concrete block strengths at 7 days. The results show the strongest compressive strength composite block (CE 28-3) was only 13% (3.13MPa) less than the strongest traditional concrete block sample. The initial crack appearance of the composite blocks were lower than the traditional blocks. Sample TC 28-2 gave lower results than Samples CE 28-2 and CE 28-3, Fig. 15.

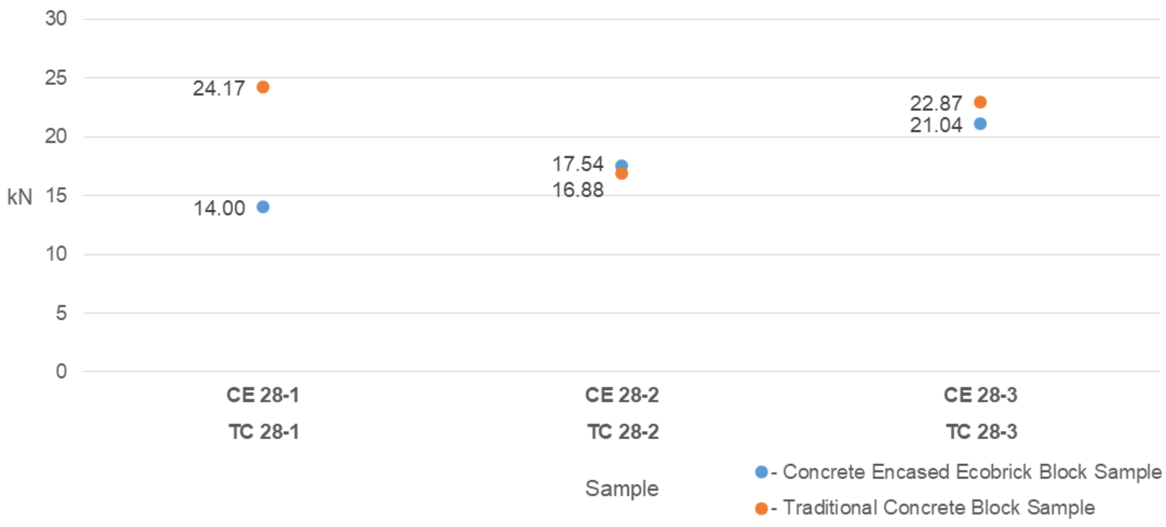


**Fig. 15. Concrete Encased Ecobrick Block Samples and Traditional Concrete Block Samples – 28 Day Compressive Strength Results Comparison.**

The initial comparison found the traditional concrete blocks after 28 days still weighed more than the composite blocks. As expected it indicates using an ecobrick filler reduces the concrete and makes a lighter block. In both data sets it shows an increased in strength over the 7 day results within their respective group. It was found the initial crack appearance of the composite blocks were considerably lower than the traditional concrete blocks, also observed at 7 days, whether this correlated to the reduced weight of the samples or the compaction method. Observations show the compressive strength of the composite blocks were greater than the 7 day traditional blocks, justified through the curing process. The 28 day results show a fluctuation between the composite and traditional block strength. Where Safinia and Alkalani found a strength increase between their composite block and comparison block. Results show the highest strengths recorded were from the traditional concrete blocks. However, it was observed that two of the composite samples were greater than one of the traditional concrete block samples. Indicating the strength of the composite blocks can reach the same values as a traditional concrete block. Which solidifies the argument that composite blocks can be used in the construction industry.

It was considered that Sample TC 28-2 could have been an anomaly in the data with the compressive strength of 16.88MPa. When compared to the other two traditional samples it was approximately 30% less. The result of Sample TC 28-2 was extremely close to the 7 day compressive strength results of the traditional concrete blocks. Although the concrete mix and methods for all blocks were the same and should not have caused any anomalies. It was noted that the sample did have some voids between the connecting cube casings, this could explain the lower compressive strength; to confirm this more samples were required for clarity.

### 4.1. Global Comparison

To understand how the concrete encased ecobrick blocks compares globally, the composite blocks were compared to the Safinia and Alkalbani study. Safinia and Alkalbani used a similar concept, comparing their composite block to the Omani hollow blocks. The composite block in their study consisted of eight empty 500ml plastic bottles encased within a 200mm x 200mm x 400mm concrete block. The initial differences were a greater sized block, unknown concrete design proportions, different concrete mix, increased quantity of plastic bottles, different plastic bottles and the testing was to an American Standard. Although there were differences present it was the closest study that could be used as a comparison. The Safinia and Alkalbani study used a British Standard concrete mix, Table 10, which aided in the comparison. The compressive strength results in the Safinia and Alkalbani study were compared to that of the composite block in this study.

**Table 10. Concrete mix design (Safinia and Alkalani, 2016).**

| Materials for concrete mix design | Value |
|---|---|
| $F_c$ | 20 N/$mm^2$ |
| Cement | Portland Cement |
| Defective | 5% |
| Slump | 50 mm |
| Fine aggregate size | 0-5 mm |
| Coarse aggregate size | 5-10 mm |
| W/C | 0.65 |

Table 11 shows the 7 and 28 day maximum load and compressive strength results of the Oman composite block. The Safinia and Alkalbani samples were labelled CB-7D (1) and CB-28D (1) which meant concrete block with plastic bottles tested at 7 and 28 days with corresponding sample number. The gross areas differed considerably with the concrete encase ecobrick blocks being 0.023m² and the Oman composite block being 0.076m².

**Table 11. Omani Composite Block Samples – 7 and 28 Day Maximum Load and Compressive Strength Results (Safinia and Alkalani, 2016).**

| Sample Reference | Maximum Load (KN) | Compressive Strength (MPa) |
|---|---|---|

| | | |
|---|---|---|
| CB-7D(1) | 458.736 | 6.036 |
| CB-7D(2) | 552.520 | 7.270 |
| CB-7D(3) | 584.744 | 7.694 |
| | | |
| CB-28D(1) | 752.400 | 9.900 |
| CB-28D(2) | 760.000 | 10.000 |
| CB-28D(3) | 775.200 | 10.200 |

The Oman composite block results after 7 days revealed the maximum loading was 584kN with the weakest being 458kN and the strongest compressive strength was 7.694MPa, the weakest being 6.036MPa. After 28 days the results showed both the maximum loading and compressive strength increased by 68%. The comparative results between the concrete encased ecobrick blocks and Oman composite blocks at 7 days, Table 12.

**Table 12. Concrete Encased Ecobrick Block Samples and Oman Composite Block Samples (Safinia and Alkalani, 2016) – 7 Day Results Comparison.**

| Sample Reference | Maximum Load (kN) | Compressive Strength (MPa) |
|---|---|---|
| CE 7-1 | 239.200 | 10.630 |
| CE 7-2 | 301.800 | 13.410 |
| CE 7-3 | 308.200 | 13.700 |
| | | |
| CB-7D(1) | 458.736 | 6.036 |
| CB-7D(2) | 552.520 | 7.270 |
| CB-7D(3) | 584.744 | 7.694 |

The 7 day comparison found the maximum loads of the Oman composite block were greater than the concrete encased ecobrick blocks, in some sample comparisons the force was double. It was found the compressive strength of the concrete encased ecobrick blocks were 127% greater than the Oman composite block, Fig. 16.

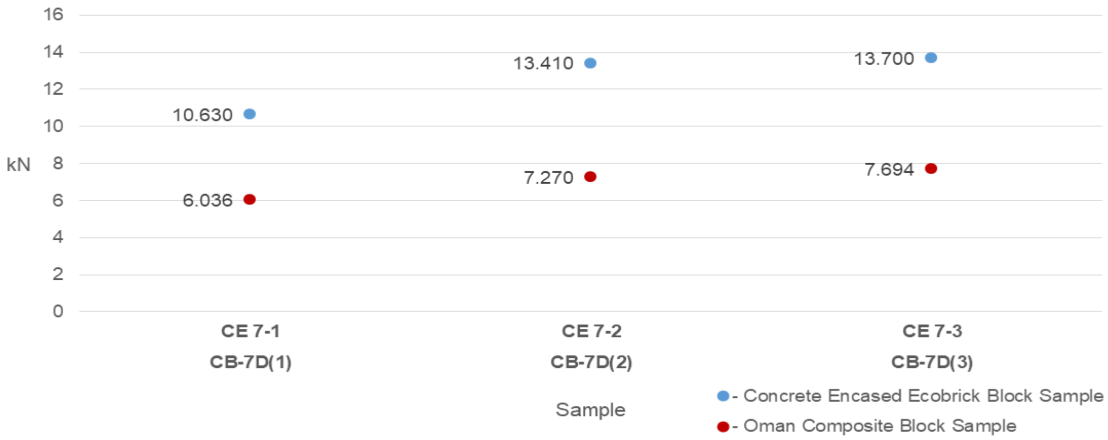


**Fig. 16. Concrete Encased Ecobrick Block Samples and Oman Composite Block Samples (Safinia and Alkalani, 2016) – 7 Day Compressive Strength Results Comparison.**

The comparative results after 28 days between the concrete encased ecobrick blocks and Oman composite blocks, Table 13.

**Table 13. Concrete Encased Ecobrick Block Samples and Oman Composite Block Samples (Safinia and Alkalani, 2016) – 28 Day Results Comparison.**

| Sample Reference | Maximum Load kN | Compressive Strength MPa |
|---|---|---|
| CE 28-1 | 315.00 | 14.00 |
| CE 28-2 | 439.70 | 19.54 |
| CE 28-3 | 473.30 | 21.04 |
| | | |
| CB-28D(1) | 752.40 | 9.90 |
| CB-28D(2) | 760.00 | 10.00 |
| CB-28D(3) | 775.20 | 10.20 |

Similar results were found after 28 days, the Oman composite block again had a greater maximum load; in some samples it was double the force of the composite block.

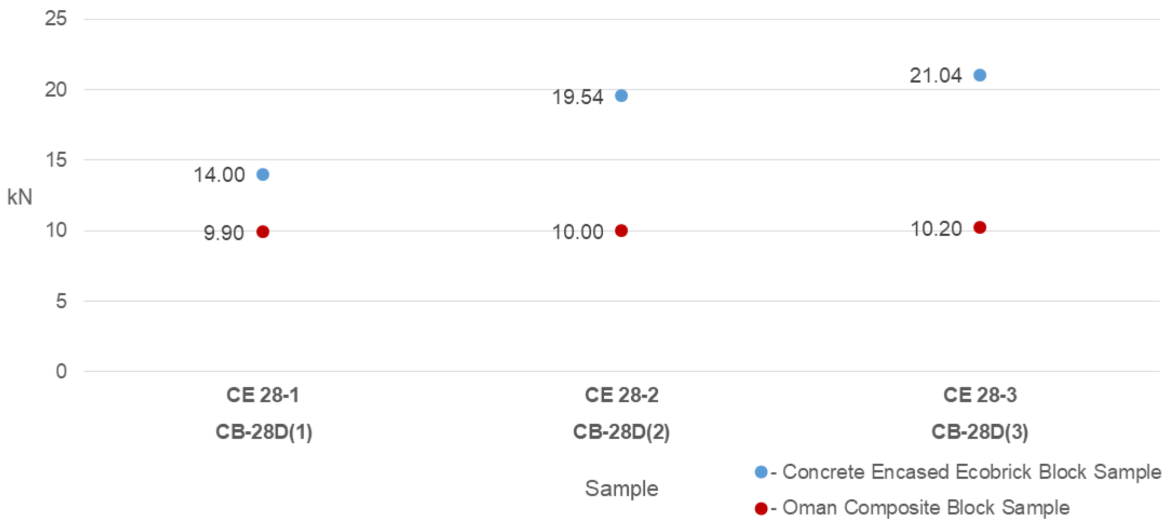


**Fig. 17. Concrete Encased Ecobrick Block Samples and Oman Composite Block Samples (Safinia and Alkalani, 2016) – 28 Day Compressive Strength Results Comparison.**

The compressive strength of the concrete encased ecobrick blocks were all greater in comparison. In some samples the composite block compressive strength was double the strength of the Oman block, Fig. 17.

Other existing studies did not match the same methodology as this research project, this caused limited comparisons regarding compressive strength results. Muyen, Barna and Hoque had a similar method of encasing multiple sand filled plastic bottles in concrete cubes. It was considered the compressive strength of the sand would be greater than the plastic waste filler and wouldn't offer a fair comparison. Oyinlola et al. used sand and water filled PET bottles encased in concrete. Their research lacked results and the filler material was not comparable. Manisha and Singh (2017) used nine bagasse filled plastic bottles encased within a concrete block. The results however were for only one composite block and gave a marginally greater compressive strength. None of the existing research referenced the standards used clearly or at all for comparison. Where Safinia and Alkalani used a similar method with standards, but with empty plastic bottles.

Initial concerns were raised over the Safinia and Alkalani sizing being accurate to fit the 500ml bottle. The study does not mention the size and shape of the 500ml bottle which causes scepticism over the bottle fitting in the block. Safinia and Alkalani accommodated eight bottles lengths ways (400mm). Meaning the bottles were to be less than 200mm in height. The width and height of the ecobrick can affect the thickness of the concrete surround, which can affect the blocks performance; the thicker the concrete the greater the stability and load distribution. The Omani comparison block was a hollow block with an unknown mix design, which justified the strength increase of the Oman composite block, as the concrete mix design of the Oman composite block could have been greater. This research project in comparison to the Safinia and Alkalani study varied in the amount of plastic bottles, no plastic fill, different concrete mix design and proportions, and block sizing. The water cement ratio in the Safinia and Alkalani study was greater which would increase the fluidity of the concrete mix. The concrete strength will decrease with an increased water cement ratio (Blake, 1994). Which was observed when the concrete encased ecobrick blocks had greater compressive strength. The Oman composite block concrete strength was 20N/mm³, a similar strength to the composite blocks of this study. This was deemed to offer a loose comparison to demonstrate where the composite blocks fit globally.

The composite blocks of this study in comparison to the Omani composite block were found to be greater in compressive strength. When tested at 7 and 28 days the Omani composite blocks had lower compressive strength results due to the difference in concrete mix design and greater area reducing the compressive stress. Further argued, the plastic filled ecobrick could provide some compressive strength in comparison to an empty plastic bottle. However, due to the larger area of the Omani composite block the maximum load was greater, in some cases double the composite block. Safinia and Alkalani found at 28 days the Omani composite block samples had a 96% compressive strength increase over the Omani hollow block. Where this study found a mixture in results between the composite blocks and the traditional concrete blocks at 28 days, Fig. 15. These findings demonstrated the composite block also had a greater compressive strength than the Oman hollow block. Which confirms that the concrete encased ecobrick blocks have greater values in global comparisons. Allowances have to be made due to the varying factors such as concrete mix, size, amount etc. However, based on these findings it can be concluded that if the Safinia and Alkalani study adopted the same methodology as this study the Omani composite block strength would increase whilst reducing the plastic waste in Oman.

### 4.2. Concrete Encased Ecobrick Block Generation

Initially this study aimed to understand ecobrick generation from UK household waste. However, it was established this data was un-obtainable and therefore it was proposed to use the plastic waste figures from Wales. To understand the potential ecobrick generation in the UK the amount of plastic waste in Wales was factored based on based on the UK population.

In Wales, the total amount of non-recyclable plastic waste collected from kerbside collections in 2019 was 35,542.128 tonnes and the total amount of non-recyclable plastic waste from litter collection was 2,634.934 tonnes. Therefore, the total amount of non-recyclable plastic waste in

Wales from 2018-19 was 38,177.062 tonne based on a population of 3.136 million in 2019. The UK population of 2019 was 66.65 million, approx. a 67% increase to Wales. Therefore, it can be estimated based on the population differences the UK produced 63,755.694 tonne in 2019.

#### 4.2.1. Plastic Bottle Volume

To understand the potential of the composite block in the construction industry, it was important to understand two things, the potential volume a plastic bottle could contain and the potential amount of natural materials saved through using said composite block. This was undertake by calculating the volume of the 500ml bottle and then finding the amount of tonnage it will hold. The volume of the PET bottle was calculated in two parts, a cylindrical base and a conical frustum. The volume under the cap was not included in the calculation due to its small volume.

Volume of 500ml PET bottle:

<u>Volume of conical frustum</u>

Eq. 1 – Conical Frustum Volume

$$= (1/3) \times \pi \times h\,(r_1^2 + r_2^2 + (r_1 \times r_2))$$

$$\text{Volume} = (1/3) \times \pi \times 0.025 \times ((0.019^2) + (0.0335^2) + (0.019 \times 0.0335))$$

$$= 5.549 \times 10^{-5}\ m^3$$

<u>Volume of cylinder</u>

Eq. 2 – Cylinder Volume

$$= \pi \times r^2 \times h$$

$$\text{Volume} = \pi \times 0.0335^2 \times 0.147$$

$$= 5.182 \times 10^{-4}\ m^3$$

<u>Total volume of the ecobrick</u>

$$5.549 \times 10^{-5}\ m^3 + 5.182 \times 10^{-4}\ m^3$$

$$= 5.737 \times 10^{-4}\ m^3$$

The total volume of the 500ml PET bottle is $5.737 \times 10^{-4}$ m³.

Now to find the volume in tonnes:

Convert to ton register

$$0.1m^3 = 0.0353146667 \text{ ton reg}$$

$$0.000573 \times 0.0353146667$$

$$= 2.023 \times 10^{-5} \text{ ton reg}$$

Then convert ton reg to metric tonne

$$2.023 \times 10^{-5} \times 0.907185$$

$$= 1.835 \times 10^{-5} \text{ tonnes}$$

Therefore, a 500ml bottle will hold approx. $1.835 \times 10^{-5}$ tonnes.

Using the total amount of plastic waste in the UK, the following is used:

Total Tonnage of plastic waste ÷ Tonnage per bottle = No. of ecobrick bottles filled
63,755.694 tonnes ÷ $1.835 \times 10^{-5}$ tonnes = 3,474,424,741 ecobricks

From the above calculations, it is evident the amount of non-recyclable plastic waste produced in the UK in 2018-19 would generate enough plastic to fill 3,474,424,741 ecobricks. Based on the dimensions of the ecobrick and composite block in this study, one ecobrick equates to one composite block, this would mean 3,474,424,741 composite blocks produced.

### 4.2.2. Material Reduction

***Concrete Block Volume***

Volume of the concrete block:

Eq. 3 – Cube Volume
Volume = Length x Width x Height
$0.300m \times 0.150m \times 0.150m = 6.75 \times 10^{-3}\ m^3$
Concrete block volume = $6.75 \times 10^{-3}\ m^3$

***Concrete Encased Ecobrick Block Volume***

The volume of the concrete encased ecobrick block can be calculated by deducting the plastic bottle volume from the concrete block:

Concrete block volume - Plastic bottle volume = Composite block volume
$6.75 \times 10^{-3}\ m^3 - 5.737 \times 10^{-4}\ m^3 = 6.176 \times 10^{-3}\ m^3$

Therefore, the concrete encased ecobrick block consists of $6.176 \times 10^{-3}\ m^3$ of concrete.

***Concrete Volume Reduction***

The concrete volume is reduced when using a 500ml plastic bottle and can be calculated by deducting the plastic bottle volume from the concrete block volume. However, it is already know from Section 4.7.2 the plastic bottle volume is $5.737 \times 10^{-4}\ m^3$, which is the same as the reduced concrete volume.

In tonnes this equates to:

$5.737 \times 10^{-4}\ m^3$ = 0.0014 tonnes

Therefore, to calculate the potential amount of concrete tonnage reduced, would be:

3,474,424,741 concrete encased ecobrick blocks x 0.0014 tonnes

= 4,864,194 tonnes

From the above calculations it can be said 4,864,194 tonnes of concrete could have been reduced in 2018-19 using the composite block in Section 2.3. Based on the mix proportions in Section 2.3 and the reduced concrete volume, the amount of reduced natural material can be calculated. Therefore by reducing 4,864,194 tonnes of concrete it would subsequently reduce 2,653,197 tonnes of aggregate, 1,326,598 tonnes of sand, 884,399 tonnes of cement and 397,980 tonnes of water.

***Concrete Volume Reduction***

A traditional concrete block with the dimensions of 300mm x 150mm x 150mm generates a weigh of 15.525kg. By introducing an ecobrick this reduces the weight of the overall block subsequently reducing the overall weight of the foundation, walls etc. When using an ecobrick the weight of the composite block is reduced by approx. 0.8kg to 14.205kg.

## 5. CONCLUSION

Following the analysis of the results obtained from undertaking the compressive strength tests on the composite blocks, it was found in comparison to the traditional concrete block after 7 days the traditional concrete block had greater strength. However, after 28 days the composite blocks had similar and greater strengths than some traditional concrete block samples. After 7 day testing a correlation was found between the strength to weight ratio of the traditional concrete block in comparison to the composite blocks. The traditional concrete blocks exhibited both greater maximum loads and compressive strengths compared to the composite block. As expected the traditional blocks would be stronger due to the void created by the ecobrick. It was further observed the maximum load and compressive strength of the strongest composite block was still weaker than the lowest strength of the traditional concrete block sample. Linking the decrease in strength to the decrease in block density, when replacing the concrete with ecobricks. There was no correlation with the initial crack appearance and increase in strength or weight. It can be said that the observed initial crack appearance was generated due to the concrete mix binding properties and potential of air voids when curing. A different mix design may have given a different observed cracking strength.

The concept of using an ecobrick filler within a concrete block was chosen due to its ease and potential. The ecobrick concept is simple for everyone to do; if the population of the UK created ecobricks at home before plastic waste disposal it generates a huge potential in the amount of building material available. If the practicality of the ecobrick concept is not suited to UK weather or as a building material. The UK could export the large quantities of the ecobricks to poverty areas for building materials; this would tackle exportation issues and marine pollution.

Interestingly, studies show the ecobrick concept ranges from plastic filled plastic bottles to plastic bricks, all of them offer ways to reduce plastic waste, which is a benefit. Innovative methods are required to combat environmental issues brought on by consumer wastage. Globally, studies suggest ecobricks are a solution to plastic waste issues and shelter in poverty areas. In terms of using concrete encased ecobrick blocks in poverty areas, this is not practical, as most poverty areas using ecobricks lack funds and access to natural resources for concrete production. Notably the ecobrick guidance suggests clean plastic waste wrappers as fill, which in poverty areas water scarcity is high and it is not practical to clean waste wrappers with water.

After 7 day testing the concrete encased ecobrick blocks reached maximum loads of 308.2kN and compressive strengths of 13.7MPa. The samples had a weight variance of 70 grams after 7 days, no correlation between the sample weight and strength was found. Taaffe et al. study observed the individual ecobrick strength increased with an increased weight. However, the ecobricks in this study were not weighed prior to concrete encasement and therefore it is unknown if the individual ecobricks expressed a ratio between strength and weight. No evidence was present in the composite blocks at 7 day testing relating to the strength and weight to clarify the Taaffe et al. research in this study.

When the composite blocks were tested at 28 days a strength increase was observed in two samples (CE 28-2 and CE 28-3), the strength had increased by 98% from the 7 day samples. Where one sample (CE 28-1) had increased by 2% from the strongest 7 day sample. Overall, it is expected that the composite block would increase in strength the longer it cured. The results at 28 days showed no strength to weight ratio increase, without knowing the weight of the individual ecobricks it is unknown if the strength of the composite block correlates to the strength of the ecobrick used. Therefore, the Taaffe et al. research cannot be confirmed through this study at 28 day testing either.

This research project was only able to undertake testing of twelve samples (six composite and six traditional); this limited the exploration of the potential the composite block has to offer. However, the results obtained show the composite block can be used for non-structural elements such as void fillers and non-loading bearing walls. The results from this study confirm that the concrete encased ecobrick blocks reach strengths similar to the traditional concrete blocks and therefore could be used in the construction industry for non-structural elements like none retaining walls and void fillers. To fully understand this composite block more testing is required. This not only includes compressive tests, but internal tensile stresses and chemical reactions between materials.

It can be concluded that this composite block can be used in the UK's construction industry for non-structural elements. It has be proved the composite block reduces the plastic waste impact and prevents natural material depletion through material reduction. The composite block meets several SDGs, whilst the ecobrick is currently a sustainable material.

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