Sustainable Low Carbon Foamed Concrete

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Sustainable Low Carbon Foamed Concrete

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Universally increased concern for sustainability, reduced carbon dioxide emissions and responsible use of resources has made governments and authorities upgrade related standards and regulations. There is no doubt, the sustainability strategies agreed and the regulations set by the authorities have a vital effect on restructuring construction industry practices. Being the most widely used construction material and therefore the most resource demanding material, concrete needs to be designed and produced responsibly. So the concrete industry has shown an 18% reduction in CO_2 emissions through the use of recycled materials and alternative fuels compared to 1990 baselines only until 2010. As the rest of the concrete industry, foamed concrete also contributes to sustainable construction effectively. Research has shown that recycled and secondary aggregate (RSA) materials can effectively replace primary aggregates or high carbon materials in foamed concrete either fully or partially, whilst maintaining the performance properties. Despite a number of risky factors such as high heterogeneity and water absorption capacity of the RSA materials used in foamed concrete, the key advantage arising from the use of these materials is their 0-3 mm particle sizes, which is not a suitable range for use in normal weight concrete. Furthermore, the study concluded that, foamed concrete can easily be recycled and used in the production of new foamed concrete.

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Keywords: Embodied carbon dioxide, Foamed concrete, RSA materials, Sustainability

INTRODUCTION

Universally increased concern for sustainability, reduced carbon dioxide emissions and responsible use of resources has made governments and authorities upgrade related standards and regulations. Like many other industries, construction industry, one of the largest users of resources, has shown ambitious progress with an increasing demand of both public and private sectors to improve their sustainable construction skills and practices. There is no doubt, the sustainability strategies agreed and the regulations set by the authorities have a vital effect on restructuring the construction industry’s practices.

As recently stated in the European Commission Construction Products Regulation, construction works need to be designed, built and demolished whilst maintaining sustainable use of natural resources. Accordingly, construction works need to be durable, the raw and secondary materials used need to be environmentally compatible and the materials and demolition wastes of construction works need to be recyclable [2].

Being the most widely used construction material and therefore the most resource demanding material, concrete needs to be designed and produced responsibly. It was reported that compared to 1990 baseline levels, UK concrete industry has shown an 18% reduction in CO_2 emissions through the use of recycled materials and alternative fuels and will exceed the target set in the UK Government Sustainable Construction Strategy for 2012. However, it should be emphasized that, the concrete industry is not only responsible for the production of low carbon concrete using responsibly sourced materials, but also for the operational and end-of-life performance of concrete. This is vital in order to minimise the CO_2 emissions, and maximize the energy efficiency of the built environment as well as minimising the waste formation [8].

Similar to the actions practised for traditional concrete products, foamed concrete is also designed, produced and specified with performance properties such that, it contributes to sustainable construction and reductions in CO_2 emissions during its production, as well as its operational and end-of-life performances.

Given its unique characteristics, foamed concrete naturally contributes to sustainable construction and reduction in CO_2 emissions. Its high air content leads to a reduction in constituent materials, flexibility in design allows for production of lower density foamed concretes further reducing the material requirement and even an elimination of the fine aggregate content. Moreover, partial or full replacement of constituent materials with recycled and secondary aggregate (RSA) materials contributes to responsible material sourcing as well as waste management. Performance properties of foamed concrete such as excellent thermal insulation and good durability [3, 4] provide additional contributions to sustainability during its operational life. Finally, when it comes to the end of its life, the potential for recycling foamed concrete minimises the demolition wastes without requiring high energy inputs for processing, given its low bonding energy [5].

Use of RSA Materials and the Effects on the Performance of Foamed Concrete

Primary aggregates, one of the main constituents of concrete, has a considerably high negative impact on the environment, therefore, minimising the use of primary aggregates by substituting them with recycled and secondary aggregates is vital [9]. Forming 28% of the UK aggregates market in 2010, recycled and secondary materials have increased their popularity [10]. A wide range of RSA materials exist which can be effectively used in normal weight concrete to replace primary aggregates. However, the silt/sand sized RSA materials are problematic due to their high water absorption and particle shapes, hence they are not suitable for using in normal weight concrete [6, 11].

Increased use of recycled and secondary aggregates that are either wastes or by-products of various processes, has also brought a new aspect to foamed concrete production improving its sustainability. According to a recent study conducted in University of Dundee [6,12], RSA materials can successfully replace primary aggregates in foamed concrete either partially or fully. Unlike normal weight concrete, RSA materials used in foamed concrete are in the range of silt/sand aggregate size, which have mean particle sizes of 0-3 mm (see Figure 1).

Figure 1 Range of RSA grades

Considering the limitations when specifying RSA materials for the production of foamed concrete, it should be emphasized that the heterogeneity of the RSA materials needs to be analysed carefully [6]. Additionally, it is also important to consider the transportation distance of the RSA materials.

Incorporation of RSA materials in concrete leads to reduced eCO_2 levels of up to 15% compared to primary aggregates if the site of origin and use is same. However, if the transportation distance of RSA materials to site of use is over 15 km, eCO_2 levels are up to 14% higher than in the case where primary aggregates are used [7]. Therefore, special care should be taken regarding the material properties and heterogeneity as well as the transportation distance before specifying the use of RSA materials.

In addition to its contribution to sustainable and reduced carbon construction through its production and service life performance, foamed concrete maintains its manner even at the end of its service life, producing no waste. When it reaches its end-of-life, foamed concrete can easily be removed and recycled without requiring high energy inputs for excavating and processing [5, 12].

EXPERIMENTAL DETAILS

First Approach: Incorporation of RSA Materials in Foamed Concrete

Foamed concretes with plastic densities ranging from 600 to 1600 kg/m³ were covered, with the main focus on 1000 kg/m³ density. Cement contents of 300 and 400 kg/m³ were used for all the mixes except from 1600 kg/m³ density mix, for which only 400 kg/m³ cement content was used. Water/cement ratio of 0.5 was used for all mixes except from 1000 kg/m³ density CR mixes. Natural sand was replaced with RSA materials at rates of 50 and 100 %. CFA and crumb rubber were not applicable for 600 kg/m³ density mix. Foamed concrete produced with natural sand and Portland cement was used as reference.

A range of RSA materials sourced from across the UK was tested for particle size distribution, density and water absorption. The effects of RSA materials on the performance of foamed concrete were evaluated in terms of consistence, seal-cured cube strength, durability and thermal conductivity. Each of RSA materials used to replace primary aggregates in foamed concrete and their mean particle sizes are outlined in Table 1. Table 2 shows the physical properties of the materials used.

Table 1 Types, sources and mean particle sizes of RSA materials [6]

TYPE	DENOTED	MEAN PARTICLE SIZE, mm	SOURCE
Demolition fines	DF	0.8	Construction demolition and excavation waste
Incinerator bottom ash	IBA	2.5	Municipal solid waste incineration
Glass fines	GF	0.5	Building flat glasses
Foundry sand	FS	0.18	Sand used in the metal casting industry
China Clay sand	CCS	0.6	Fines from China Clay waste
Conditioned fly ash	CFA	0.02	Coal combustion (water addition for conditioning)
Crumb rubber	CR	1.0	Shredded truck tyres

Table 2 Physical properties of RSA materials used in foamed concrete [6]

	NATURAL SAND	DF	IBA	GF	FS	CCS	CFA	CR
Particle density in SSD state, g/cm³	2.63	2.18	1.95	2.36	2.08	2.61	2.04	1.07
Water absorption, % by mass	0.50	8.83	10.97	0.01	6.03	0.58	†	0.75

† Not applicable

Recycling potential of foamed concrete

Recycling potential of foamed concrete was assessed using RSA foamed concrete demolition wastes. Demolished foamed concrete was broken with a hammer and crushed in a ball mill to the size of material 95-100% passing through the 4.75 mm sieve.

The tests were carried out with 1000 kg/m³ density mixes in order to assess the use of recycled foamed concrete in the production of new foamed concrete. Evaluated properties of foamed concrete produced with recycled foamed concrete aggregates were plastic density, slump spread and seal-cured cube strength [12].

Second Approach: Embodied Carbon Dioxide (eCO_2)

As a second approach, embodied CO_2 of foamed concretes arising from the production were calculated using the eCO_2 figures for the constituent materials given in [7] and the mix design method given in [4]. ECO_2 arising from the transportation of materials was not included in the calculations. Foamed concretes produced with densities ranging from 200 to 1600 kg/m³, 300 kg/m³ cement content and water/cement ratio of 0.5 were evaluated. ECO_2 calculations were performed on both 100% Portland cement and 70% Portland cement, 30% coarse fly ash (conforming to BS EN 12620 [1]) mixes.

RESULTS AND DISCUSSIONS

Incorporation of RSA Materials in Foamed Concrete

- Flow characteristics of RSA foamed concretes were comparable with sand foamed concrete except for foamed concrete containing 100% CR and 300 kg/m^3 cement content, as a result of the low particle density of crumb rubber. Above 1000 kg/m^3, slump flow was reduced. This is thought to occur as a result of the reduced foam/paste phase offsetting the effect of increased self-weight (see Figure 2).

- Cube strengths of RSA foamed concretes were similar to sand foamed concretes. The material density of RSA materials is an important factor affecting strength. Given RSA materials with low density and water absorption resulted in higher strengths at all ages compared to the high density and water absorption materials.

- Although variations occur with changing RSA type and percent level replacement, drying shrinkage strain of RSA foamed concretes were generally higher. Although it is difficult to compare, RSA foamed concretes showed similar resistance to sulfate attack. Results for drying shrinkage and resistance to sulfate attack suggested further work is required.

- In terms of indicative thermal conductivity, RSA foamed concretes performed similar to sand foamed concrete, suggesting that thermal conductivity is more dependent upon the density of foamed concrete Thermal conductivities obtained for the range of foamed concrete densities tested were found to be between 0.1 and 0.7 W/mK (see Figure 3).

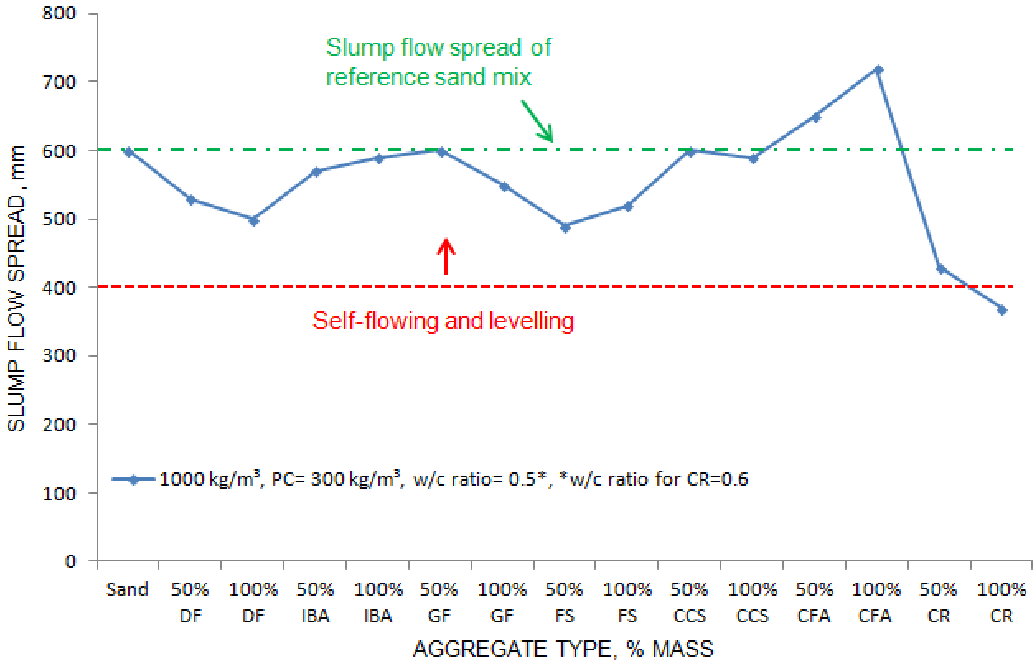


Figure 2 Relationship between aggregate type and slump flow [6]

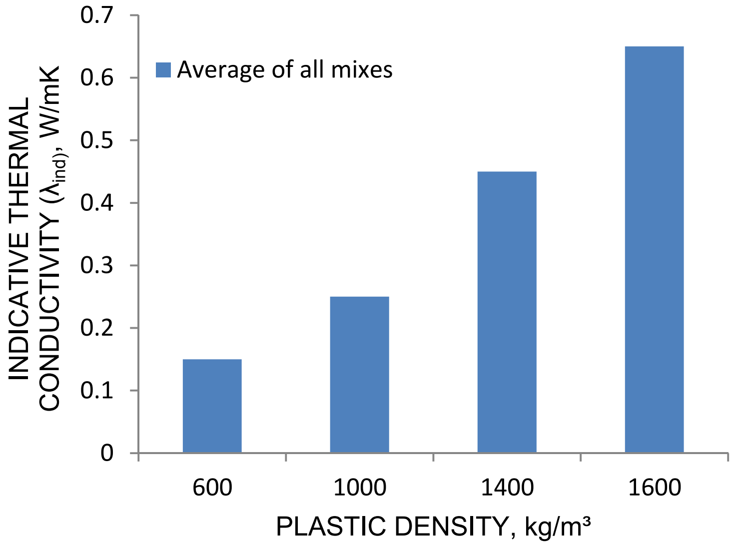


Figure 3 Effect of plastic density on indicative thermal conductivity of foamed concrete [6]

Recycling Potential of Foamed Concrete

- Increased number of crushing cycles improved the performance properties of foamed concrete produced with recycled foamed concrete aggregates (see Table 3).

- Possibly, the improved consistence resulted from the additional water added to cover the high water absorption capacities of the recycled foamed concrete aggregates. At the time when the consistence was measured the additional water may not have been fully absorbed, resulting in higher consistence.

- It is thought, the increased strengths may have resulted from the hydration of un-hydrated cement particles existing in the recycled foamed concrete aggregates.

Table 3 Effect of the number of recycles on the performance of foamed concrete [5,12]

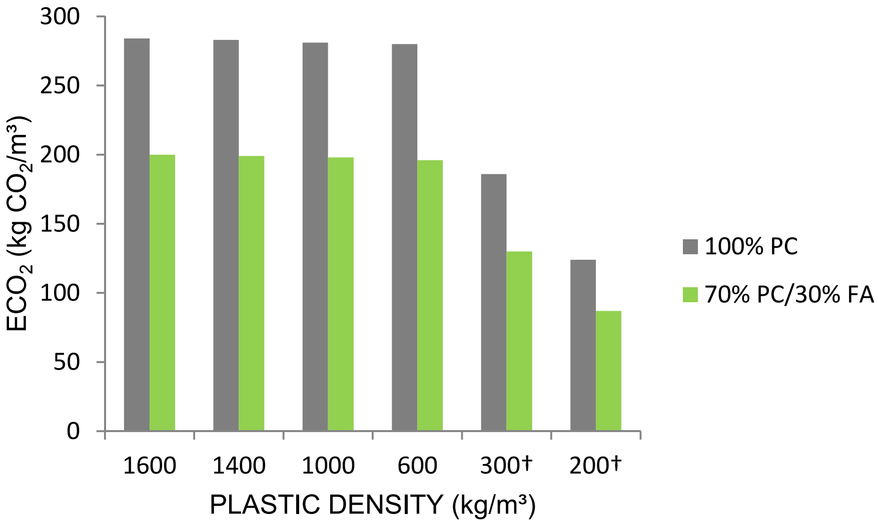
NUMBER OF CRUSH/RECYCLE	FOAMED CONCRETE PROPERTIES			
	Plastic density (kg/m^3)	Slump spread (mm)	Cube strength (MPa)	
			7-days	28-days
0	1035	520	0.5	0.6
1	985	700	0.6	1.3
2	1020	700	1.1	1.7
3	1010	700	1.5	2.9
4	990	710	1.6	3.2
5	1015	705	1.7	3.5
6	1030	710	1.7	3.9

Embodied carbon dioxide (eCO_2)

- Partial replacement of PC with 30% FA reduced the eCO_2 by approximately 30% (see Figure 4).

- Designed plastic density, therefore, the cement content is the governing factor for the eCO_2. Reducing the density from 1600 to 200 kg/m^3 reduced the eCO_2 by around 57% which is 160 kg of CO_2 per 1 m^3 of foamed concrete (see Figure 4).

- Including the eCO_2 arising from the transportation of the materials may greatly change these eCO_2 levels calculated.



† Cement contents are 200 and 133 kg/m³ respectively, no aggregates used

Figure 4 Effect of partial replacement of PC with fly ash on eCO_2 of foamed concrete

CONCLUSIONS

- RSA materials can effectively be used in foamed concrete without adversely affecting the performance properties.
- The properties of RSA materials have a significant effect on the performance of foamed concrete. Therefore, careful assessment of material properties is vital.
- Similar to the reference foamed concrete, RSA foamed concretes were found to increase the energy efficiency of the built environment, possessing very good thermal insulation properties. Therefore, it is concluded that thermal conductivity is more dependent on the plastic density of foamed concrete.
- Foamed concrete demolitions can easily be processed and recycled to be used as recycled aggregates, resulting in zero waste at the end of its life cycle.
- Through careful specification of foamed concrete, reductions up to 57% in eCO_2 can be achieved per 1 m^3 of foamed concrete.
- Calculated eCO_2 figures suggested that, by specifying low density foamed concretes, where applicable, eCO_2 can be reduced significantly.

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