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FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE BEAMS CONTAINING EXPANDED GLASS AS LIGHTWEIGHT AGGREGATES

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Abstract

The flexural properties of reinforced concrete beams containing expanded glass as a partial fine aggregate (sand) replacement are investigated. Four concrete mixes were employed to conduct this study. The fine aggregate was replaced with 0%, 25%, 50% and 100% (by volume) expanded glass. The results suggest that the incorporation of 50% expanded glass increased the workability of the concrete. The compressive strength was decreasing linearly with the increasing amount of expanded glass. The ductility of the concrete beam significantly improved with the incorporation of the expanded glass. However, the load-carrying capacity of the beam and load at which the first crack occurs was reduced. It was concluded that the inclusion of expanded glass in structural concrete applications is feasible.

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Key words

- Expanded glass,
- lightweight aggregate,
- reinforced concrete,
- flexural behavior.

1 INTRODUCTION

Recent research has shown that the replacement of sand with lightweight aggregates shows a marginal difference in the 28 days compressive strength, depending upon the amount of the replacement used. The replacement of recycled fine aggregate up to 20% or recycled coarse aggregate up to 30% produced an acceptable concrete (Khatib, 2005; Debieb and Kenai, 2008). The reduction of natural sand and replacing it with a lightweight material reduces the self-weight of the structure, thus reducing the size of the structural elements or allowing higher buildings to be constructed (Kralj, 2009; Khatib et al., 2012). This in turn will provide a commercial benefit, as lower quantity of materials will lower the cost of the building. The use of waste materials in construction applications is advantageous in that they can produce a material (e.g., concrete) of adequate performance as well as offer economic and environmental benefits (Khatib & Mangat, 2002; Khatib and Mangat, 2003; Mangat et al., 2006; Hadjsadok et al., 2012; Kenai et al., 2013; Khatib et al., 2013; Khatib 2014, Khatib et al., 2014). For example, replacing fine or coarse recycled aggregates could lead to a decrease in the amount of waste material sent to landfills and also reduce the amount of natural materials which are commonly used in concrete (Maier and Durham, 2012; Menadi et al., 2013). There are added cost savings, in that the UK landfill tax continues to increase, reaching £80 per tonne in 2014 compared with £72 in 2013 (Letsrecycle, 2012).

Lightweight concrete containing recycled expanded glass as an aggregate can be used on its own in construction, but not as a load-bearing structure. It was found that concrete made with expanded glass had very good thermal conductivity; hence, it can be recommended as a coating material during construction (Poraver, 2012).

Expanded glass is obtained by crushing the glass into a powder and mixing it with water and expanding agents and placing it in a furnace at 900° C. Through this process expanded glass is produced (Poraver, 2012). Expanded glass with different sizes can be produced. For the purpose of this research, sizes between 1-2 mm and 0.5-0.25 mm were used, which were considered to be suitable to replace the sand.

This paper investigates the performance of expanded glass in reinforced concrete applications. It reports the results of an experimental investigation on the flexural behavior as well as the compressive strength of reinforced concrete containing a full or partial replacement of fine aggregate with expanded glass.

Tab. 1 *Details of the concrete mixes.*

		Quantity (kg/m^3)					
Test/Mix No.	Type	Cement	Water	FA	CA	FEG	W/C
1	FEG0 (Control)	375	188	646	1199	0	0.50
2	FEG25	375	188	485	1199	31	0.50
3	FEG50	375	188	323	1199	61	0.50
4	FEG100	375	188	0	1199	122	0.50

2 EXPERIMENT

2.2 Materials and mixes

The materials used in this work were; cement, coarse aggregate of a 20 mm nominal size, fine aggregate (sand) of a 5 mm maximum size, foamed expanded glass of 0.2-1 mm size and water. Four concrete mixes were used in this study. The control (FEG0) has a proportion of 1 (cement): 1.7 (fine aggregate): 3.2 (coarse aggregate) by weight. In the mixes FEG25, FEG50 and FEG100, the fine aggregate was replaced with 25%, 50% and 100% foamed expanded glass (FEG) respectively (by volume). The free water to cement (W/C) ratio was maintained constant at 0.5 for all mixes. Due to the fact that expanded glass is a porous material it absorbs more water than natural sand; therefore more water was added to compensate for the absorption of the aggregate. Further details about the mixes are given in Table 1.

2.2 Preparation of the specimens and Curing

The reinforcement that was used in this project is 6 mm diameter mild steel. The reinforcement was kept constant for all the beams to investigate the effect of the expanded glass on the flexural behaviour of the reinforced concrete beam. For this experiment a plywood mould with dimensions of 700 mm x 150 mm x 100 mm beams and steel cubes with the dimensions of 100 mm x 100 mm x 100 mm conforming to BS EN 12390-2 were used. The dimensions and the arrangement of the reinforcement of all the beams can be seen in Fig. 1.

For achieving good compaction and reducing air voids, the concrete was poured in stages, and a concrete vibrator was used. Once the beams and cubes were cast, they were left for one day in the moulds and covered to reduce any dissipation of the water. After 24 hours, the beam and cubes were de-moulded and kept at a room temperature of 20±2°C for a period of 27 days (i.e., a total curing period of 28 days). In order to prevent moisture losses, the concrete beams and cubes were covered with plastic sheeting.

2.3 Testing

The compressive strength testing of the concrete cubes was commenced in accordance with BS EN 12390-3:2009, Part 3: Compressive strength of test specimens (BS EN 12390-3, 2009). The testing machine used conformed to BS EN 12390-4, and the loading increment was in a range of 0.6 ± 0.2 MPa/s. The load was applied steadily until the failure of the concrete cube. The maximum load and strength were recorded in kN and MPa respectively.

The beams were tested under four point loads, i.e., two loads acting on the beam at the top and two reactions on both sides. The test was done in accordance with BS EN 12390-5:2009, Part 5: Testing hardened concrete (BS EN 12390-5, 2009). Fig. 1 shows the loading arrangement. Four demec points were attached to the front side of the beam to measure the strain under the increasing load. A total of four positions was used as shown in Fig. 2. Two pairs of demec points were located in the upper half of the beam and two in the lower half to give a good indication of the flexural behaviour of the reinforced concrete beam.

The testing machine that was used in this investigation conformed to EN 12390-4 standards. The loading was applied in increments of 2 kN until the failure of the beam allowing taking deflection and strain readings for all concrete mixes.

3 RESULTS AND DISCUSSION

Fig. 3 shows the slump results for the concrete containing varying amounts of FEG. It can be observed that there was an increase in the slump as the amount of FEG increased up to a 50% sand replacement. However, there seemed to be a sudden drop in the slump to zero at 100% replacement. The improvement in the workability may be due to the spherical shape of the expanded glass. It is not too clear why the slump dropped at the 100% sand replacement. However, the slump of all the concretes was below 60 mm.

Fig. 4 plots the density of the concrete mixes incorporating different contents of FEG as a replacement for fine aggregate at 28 days of curing. The density of the concrete decreases as the greater volume

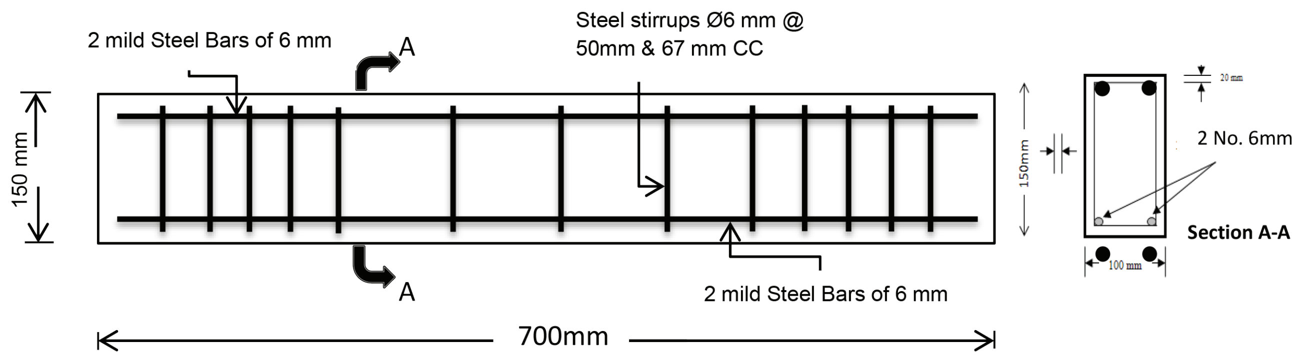

Fig. 1 *Reinforcement details and cross-section of the beam.*

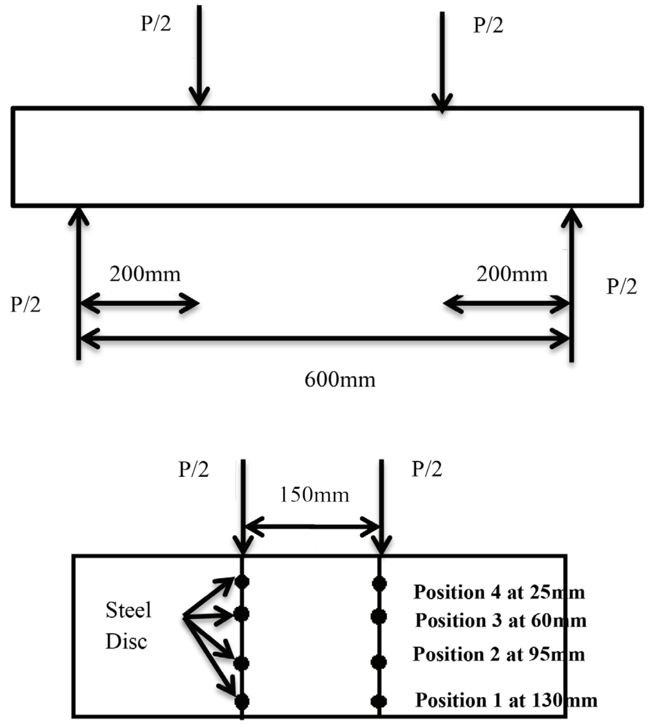

Fig. 2 *Loading pattern and locations of strain gauges.*

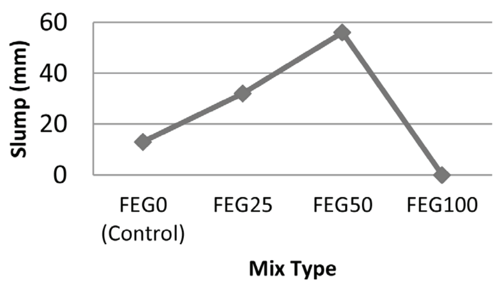

Fig. 3 *Slumps for the concrete containing varying amounts of FEG.*

of fine aggregates is replaced with the expanded glass. The density of the mix containing 50% of the expanded glass was 2167 kg/m^3 compared with 2313 kg/m^3 for the control. This is approximately a drop of 7% in the self-weight of the beam. The full replacement of the fine aggregates with the expanded glass resulted in a self-weight reduction of 13%. The fact that the self-weight of the beam was not influenced dramatically is primarily governed by the smaller proportion of the fine aggregates compared to the coarse aggregates.

The compressive strength at 28 days of curing for the concrete containing varying amounts of FEG as a replacement for the fine aggregate is shown in Fig. 5. It can be observed that there is a constant decrease in the compressive strength as a greater percentage of the expanded glass is incorporated. By replacing 100% of the fine aggregates with the expanded glass it was still possible to achieve a compressive strength of more than 32 N/mm^2 (the minimum strength for structural concrete is 18N/mm^2) and reduce the self-weight of the concrete by 13%. The replacement of 25% of the fine aggregates with the expanded glass resulted only in a marginal reduction of the compressive strength of 7%. This finding is also in agreement with results obtained elsewhere (Khatib 2005). It is worth highlighting the fact that the density has a direct relationship on the compressive strength of the concrete; i.e., a decrease in the compressive strength is associated with a decrease in the density (Meddah 2010).

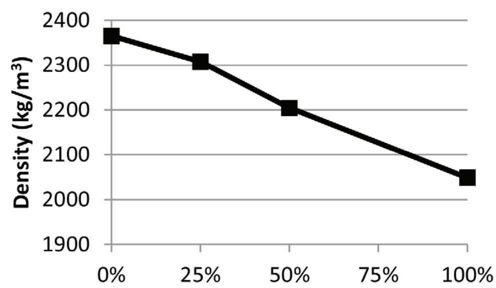

Fig. 4 *Density of concrete at 28 days for concretes containing varying amounts of FEG.*

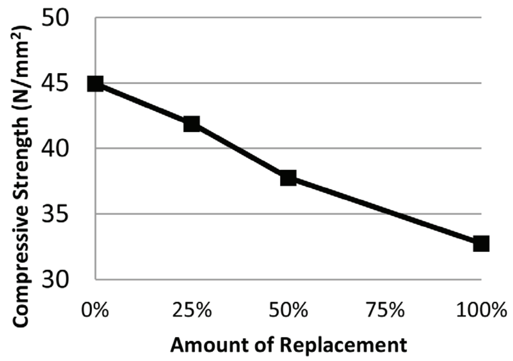

Fig. 5 *Compressive strength at 28 days for concretes containing varying amounts of FEG.*

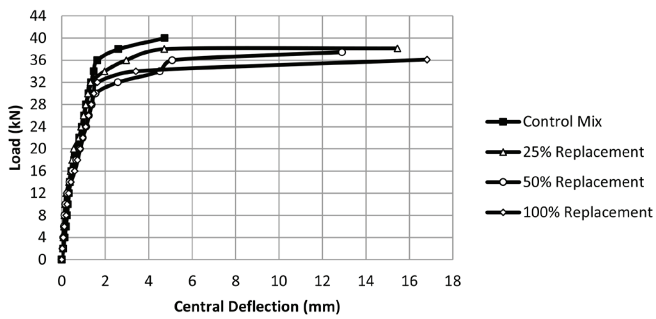

Fig. 6 *Load versus central deflection for beams containing varying amounts of FEG.*

Fig. 6 shows the load versus the central deflection for the concretes containing 0, 25, 50 and 100% FEG as a sand replacement respectively at 28 days of curing. It can be observed that the ductility of the beam increases and reaches its maximum value of deflection of about 17 mm when 100% of the fine aggregates is replaced compared with a deflection of less than 5mm for the control (i.e., 0% FEG). This indicates that the maximum deflection at 100% FEG is more than 3 times that of the control. For all of the mixes, the relationship between the load and central deflection was linear until the first crack. It continued to be linear with a different slope until the yielding of the steel. Once the yielding point was reached, the incorporation of the expanded glass influenced the maximum central deflection of the beam.

The load at which the first crack appeared for all the concrete mixes is shown in Fig. 7. As can be expected, the cracks were developing in the tensile zone and spreading to the top of the beam. The cracks were mostly in the middle part of the beam when the load was be-

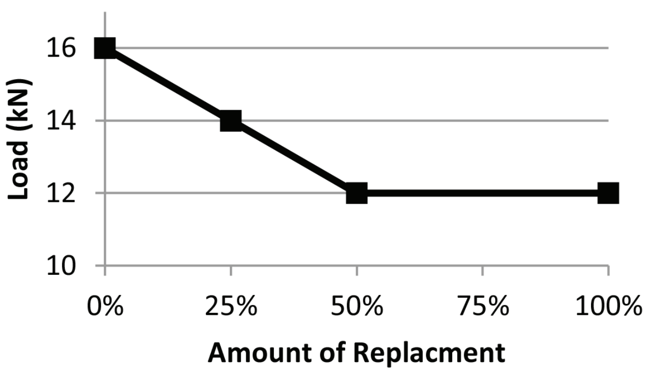

Fig. 7 *Load at the first crack for beams containing varying amounts of FEG.*

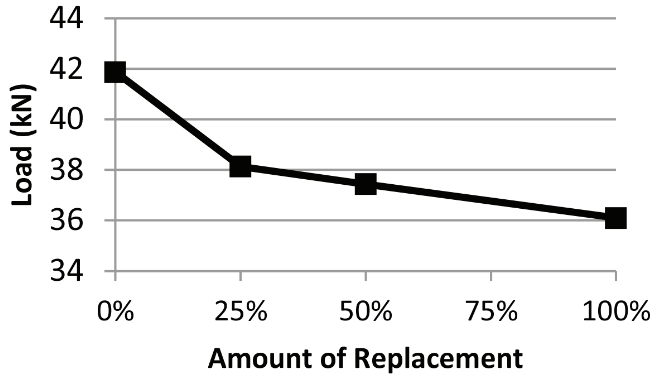

Fig. 8 *Ultimate load for beams containing varying amounts of FEG.*

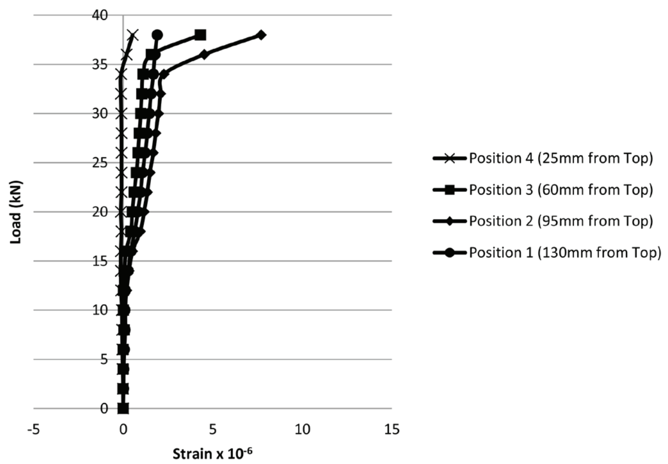

Fig. 9 *Strain vs. Load for a beam with a 0% FEG replacement.*

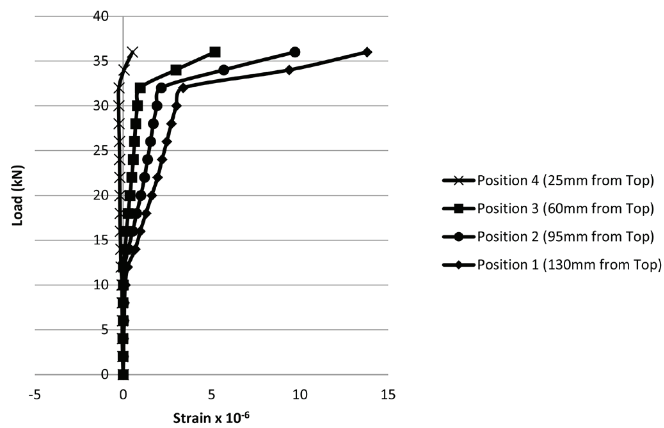

Fig. 10 *Strain vs. Load for a beam with a 25% FEG replacement.*

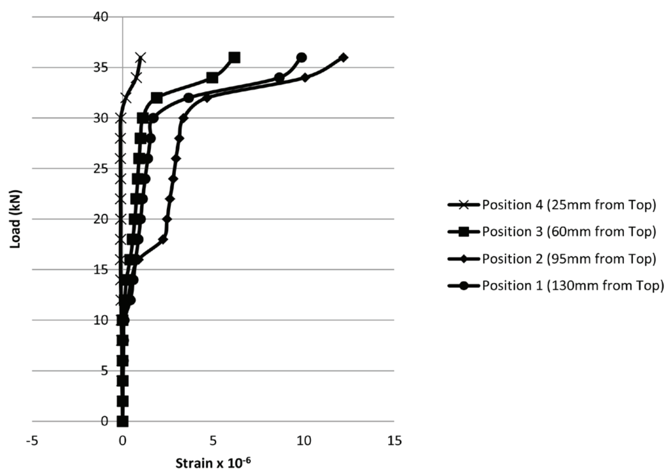

Fig. 11 *Strain vs. Load for a beam with a 50% FEG replacement.*

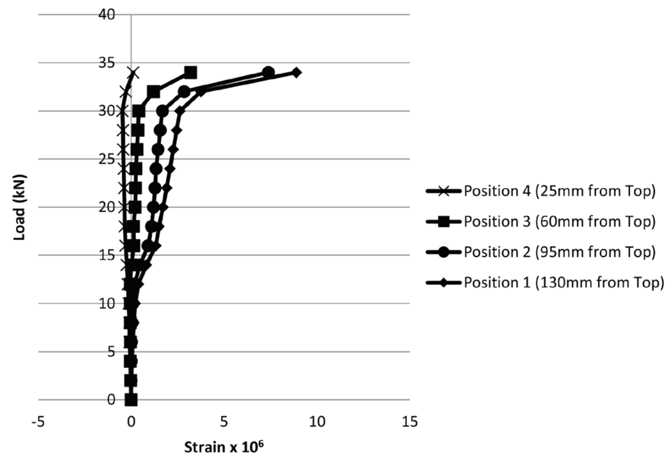

Fig. 12 *Strain vs. Load for a beam with a 100% FEG replacement.*

tween 20 and 30 kN, depending upon the concrete's strength. As the percentage of expanded glass increases, there is a decrease of the load at which the first crack occurs. The same behaviour has been noticed elsewhere (Khatib et al, 2012).

Fig. 8 plots the load at failure for concretes beams with different amounts of FEG. As the amount of the fine aggregate replacement with FEG is increased the ultimate load decreases systematically. There is a sudden drop in the ultimate load-carrying capacity at the 25% FEG replacement. However, the drop is a smaller drop beyond that level of replacement. Similar behaviour has been reported elsewhere (Khatib et al. 2012). It is worth noticing that the compressive strength of the concrete has a direct relationship with the carrying capacity of the beam in that a decrease in the compressive strength results in a decrease in the ultimate load.

Figs. 9 to 12 plot the strain at different locations along the depth of the beam for concrete containing 0%, 25%, 50% and 100% FEG respectively. Initially and at lower loads, the strain at the top position of the demec points experience compression, while and the rest is in tension. As the load increases, the tensile zone increases, and most of the locations show tensile stresses developing. This causes the neutral axis to move upwards with the increase in load. As the percentage replacement of the fine aggregate with FEG increases, the maximum strain increases, indicating an enhanced ductility.

The replacement of the fine aggregates resulted in a similar failure mode as for the control beam. Cracks were developing in the middle part of the beam just outside the position of the point loads. As the load was increasing, the bending moment was increasing. This caused cracks to propagate towards the top of the beam, eventually, they caused the failure of the beam as can be seen in Figs. 13-16, where a visual observation was made on the failure pattern for the concretes containing varying amounts of FEG. Also, shearing cracks were occurring in beams containing 50% and 100% replacements of the fine aggregate. Crack propagation was slow until the yielding of the steel, where a gradual increase in the crack size occurred, followed by a complete failure.

Fig. 13 *Failure of the beam containing 0% of FEG.*

Fig. 14 *Failure of the beam containing 25% FEG.*

Fig. 15 *Failure of the beam containing 50% FEG.*

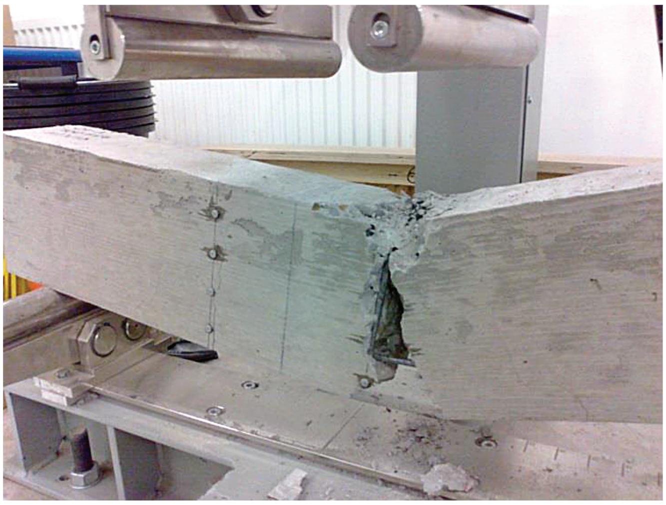

Fig. 16 *Failure of the beam containing 100% FEG*

CONCLUSIONS

The replacement of fine aggregates with 50% of the expanded glass increased the workability of concrete. Beyond 50%, the slump is drastically reduced. The compressive strength gradually reduces as the percentage of expanded glass incorporated within the mix increases. However at a 100% replacement of the fine aggregates, the compressive strength met the minimum requirements of 17MPa for structural concrete applications. The expanded glass improved the ductility of the reinforced concrete beam as a greater central deflection was achieved when FEG was present. The presence of FEG slightly decreased the load at which the first crack occurred and the load-carrying capacity of the beam.

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REFERENCES

British Standards Institution – BS EN 12390-3:2009 (2009) *Testing hardened concrete. Part 3: Compressive strength of test specimens*.

British Standards Institution – BS EN 12390-5:2009 (2009) *Testing hardened concrete. Part 5: Flexural strength of test specimens.*

Dbieb, F. – Kenai, S. (2008) *The use of coarse and fine crushed bricks as aggregate in concrete*, Construction and Building Materials, 22(5), pp. 886-893.

Hadjsadok, A. – Kenai, S. – Courard, L. – Michel, F. – Khatib, J.M. (2012) *Durability of mortar and concrete containing slag with low hydraulic activity*, Cement and Concrete Composites, 34(5), pp. 671-677.

Kenai, S. – Menadi, B. – Khatib, J.M. (2013) *Sustainable construction and low-carbon dioxide concrete: Algeria case*, Engineering Sustainability Journal-Proceedings of the ICE, 167(2), pp. 45-52.

Khatib, J.M. – Mangat, P.S. (2002) *Influence of high-temperature and low-humidity curing on chloride penetration in blended cement concrete*, Cement and Concrete Research, 32(11), pp. 1743-1753.

Khatib, J.M. – Mangat, P.S. (2003) *Porosity of cement paste cured at 45 C as a function of location relative to casting position*, Cement and Concrete Composites, 25(1), pp. 97-108

Khatib, J.M. (2005) *Properties of concrete incorporating fine recycled aggregate*. Cement and Concrete Research, 35(8), pp. 763–769.

Khatib, J.M. (2014) *Effect of initial curing on absorption and pore size distribution of paste and concrete containing slag*, Korean Society for Civil Engineers (KSCE) Journal, 18(1), pp. 264-272.

Khatib, J.M. – Shariff, S. – Negim, E.M. (2012) *Effect of Incorporating Foamed Glass on the Flexural Behaviour of Reinforced Concrete Beams.* World Applied Sciences Journal, 19(1), 2012. pp. 47–51.

Khatib, J.M. – Mangat, P.S. – Wright, L. (2013) *Early age porosity and pore size distribution of cement paste with flue gas desulphurization waste*, Journal of Civil Engineering and Management, 19(5), pp. 622-627.

Khatib, J.M. – Mangat, P.S. – Wright, L. (2014) *Pore size distribution of cement pastes containing fly ash-gypsum blends cured for 7 days*, Korean Society for Civil Engineers (KSCE) Journal, 18(4), pp. 1091-1906.

Kralj, D. (2012) *Experimental study of recycling lightweight concrete with aggregates containing expanded glass*. Process Safety and Environmental Protection, 87(3), pp. 267-273.

Letsrecycle.com (2012) *UK glass recycling rate remains below EU average* [online]. London: Letsrecycle.com. [Accessed 6 September 2014]. Available at: <http://www.letsrecycle.com/news/latest-news/glass/uk-glass-recycling-rate-remains-below-eu-average>.

Maier, L.P. – Durham, S.A. (2012) *Beneficial use of recycled materials in concrete mixtures*. Construction and Building Materials, 29(3), pp. 428-437.

Mangat, P.S. – Khatib, J.M. – Wright, L. (2006) *Optimum utilization of FGD waste in blended binders*, Proceedings of the ICE-Construction Materials Journal, 1(2), pp. 60-68.

Meddah, M.S. – Zitouni, S. – Belaabes, S. (2010) *Effect of content and particle size distribution of coarse aggregate on the compressive strength of concrete*. Construction and Building Materials, 24(4), pp. 505-512.

Menadi, B. – Kenai, S. – Khatib, J.M. (2013) *Fracture behavior of concrete containing limestone fines*, Proceedings of the ICE-Construction Materials Journal, 167(3), pp. 162-170.

Poraver (2014) *Production Process* [online]. Schlüsselfeld: Poraver [Accessed 6 September 2014]. Available at: < http://poraver.com>.