Concrete manufacture with un-graded recycled aggregates

A.E. Richardson, K. Coventry and S. Graham
University of Northumbria, Newcastle upon Tyne, UK

Abstract

Purpose – The purpose of this paper is to investigate whether concrete that includes un-graded recycled aggregates can be manufactured to a comparable strength to concrete manufactured from virgin aggregates.

Design/methodology/approach – A paired comparison test was used to evaluate the difference between concrete made with virgin aggregates (plain control) and concrete including recycled waste. Un-graded construction demolition waste and un-graded ground glass were used as aggregate replacements. With regard to concrete, compressive strength is widely used as a measure of suitability as being fit for purpose. Therefore compressive strength was mainly used to compare the different concrete batches; however density was measured across the range of samples.

Findings – The findings show that a lower average compressive strength is achieved when compared to the plain control sample manufactured with virgin aggregates. Correct particle packing may not be achieved and grading of aggregates is essential prior to mix design. The recycled aggregate was highly variable in terms of the fine particle content, which affected the water demand of the concrete.

Practical implications – This manufacturing practice is considered necessary because of the current trend in using waste products in concrete to replace binders and aggregates; thus reducing the impact on the environment and use of finite natural resources. The research shows the risk of mixing concrete using a simple aggregate replacement without careful aggregate grading and adjustments to the mix design.

Originality/value – The paper examines 100 per cent ungraded aggregate replacement with glass and demolition waste.

Keywords Waste recovery, Aggregates, Glass, Compressive strength, Cements and concretes Paper

type Research paper

1. Introduction

In the UK the demand for aggregates for all uses is approximately 270 million tonnes per year, with 70 million tonnes of this demand coming from secondary and recycled aggregates (BRMCA, 2008). If 70 million tonnes of material is being recycled per year, there needs to be a suitable supply chain to ensure continuity of supply and price stability in the recycled aggregate market. Ensuring a supply chain of recycled aggregates affords many potential gains, achieved through; reducing the material volume transported to already over-burdened landfill sites, possible cost reductions to the contractor/client when considering the landfill tax saved and the potential for lower cost aggregate replacements, a reduction in the environmental impact of quarrying and the saving of depleting natural aggregate resources.

Recycled aggregate usage is not however advisable without consideration of the pertinent differences its inclusion brings to concrete mix design. Sagoe and Brown (2002) have concluded that the density of recycled concrete aggregate is lower than that of virgin aggregate concrete due to the occurrence of porous residual mortar lumps within the demolished material. Collins (1994) states that as the structure of recycled aggregate may contain voids and therefore it is usually the case that a higher water content is required to achieve a good standard or workability. Poon et al. (2008) verify the reduced workability and dimensional stability exhibited by concrete formed from recycled fine aggregates (,5mm) which results from higher water adsorption (.10 per cent). British Ready-Mixed Concrete Association (BRMCA) (2008)2 suggest that if demolition waste is used as an aggregate replacement, this will significantly increase the cement content and discredit the sustainability credentials of employing waste aggregate. This problem may be ameliorated with the use of a super plasticiser to reduce the water cement ratio and achieve similar compressive strengths, although this is beyond the scope of this paper.

The focus of this paper is to examine the effects of recycled waste, specifically recycled glass cullet and recycled aggregate, in concrete production utilising the compressive cube strength as a means by which to assess concrete quality. The lack of general material consistency attributed to material waste is shown to result in inconsistent concrete quality as evidenced by the quantitative data herein. This study has avoided the adoption of finely powdered glass to avoid the risk of inducing alkali silica reaction when utilising fine glass as a partial cement replacement (Byars et al., 2004).

2. Potential waste supply chains

The construction industry is the UK's largest industry comprising the sectors shown in Figure 1 and it is the largest contributor to landfill waste. DEFRA, (2004, cited in

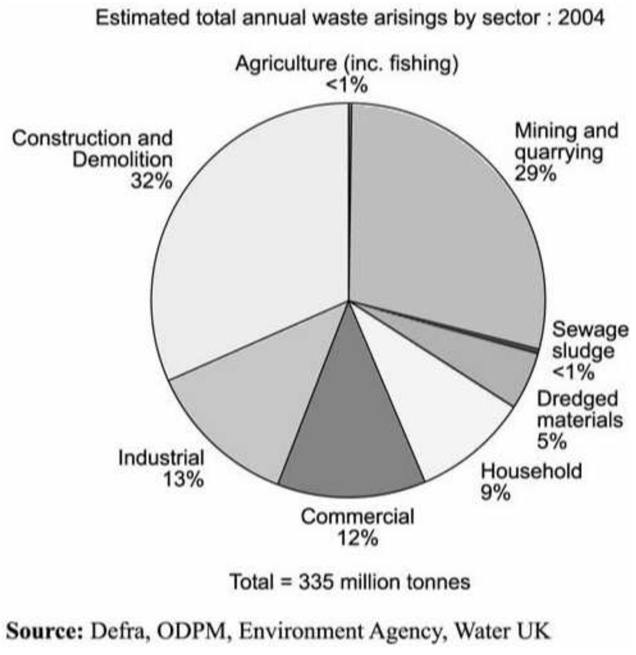


Figure 1. Annual waste by sector, 2004

Friends of the Earth, Durham, 2004) calculated that 32 per cent of the UK's waste came from the construction and demolition sector as shown in Figure 1.
Figure 1 shows that 1,07.2 million tonnes of waste is produced in the UK construction industry alone. If some of the demolition waste can be recycled this would reduce the overall impact on limited landfill sites.

Waste arriving on landfill sites is subject to landfill tax which was initiated to encourage contractors to reduce their waste output and to use alternative forms of waste management. The tax is paid on top of normal landfill fees by contractors and local authorities who want to dispose of waste on landfill sites. It is therefore a cost saving to the contractor not having to pay tax by recycling.

2.1 Aggregate sourcing

Recycled aggregate is aggregate resulting from the processing of inorganic material previously used in construction, e.g. crushed concrete, masonry, brick. These materials are generally reclaimed from the demolition of buildings, roads and bridges. Traditionally, the application of recycled aggregate is used as landfill cover but today, technology has improved so that there can be many different applications for recycled aggregates.

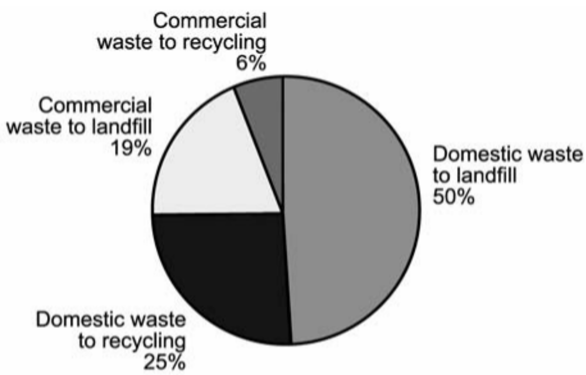
Glass (2001) mentions that aggregates account for approximately 90 per cent of a concrete mix, by volume and there are significant amounts of potential aggregate sources to be found in demolition waste to supply this need. Hughes et al. (2004) have commented that demolition waste could be used as coarse aggregate in concrete, thus reducing the depletion of existing aggregate resources.

Despite the obvious benefits of using recycled aggregates in the construction industry, the majority of construction projects still use virgin sources for concrete manufacture. One of the reasons for this was found in a study by Otaka (2000) in which the price of ordinary Portland cement (OPC) was shown not to have risen significantly for the past 30 years while its quality has remained high; because of the efficient mass production of natural aggregates, the cost for construction companies to buy them has remained low.

2.2 Sourcing glass

There is a substantial supply of suitable glass waste to allow widespread use in concrete. The UK produces 3.3 million tonnes of glass annually and of this, 1.26 million tonnes are recycled (WRAP, 2007). Despite this recycling effort, glass is still dumped in landfill when it is of poor quality or mixed colour and it is this glass that will prove cost effective for use as replacement aggregate in construction products. Data reproduced in Figure 2 illustrate that 69 per cent of the domestic and commercial glass waste is destined to contribute to landfill waste with only 31 per cent being recycled.

The recycling of glass occurs through systemised collection of glass around the country which is delivered to the processing plant. The glass is sorted into individual colours (clear, green and brown). Glass is run through a conveyor belt where operatives remove any foreign objects such as stones or plastic. The glass is then crushed in a machine to around 50mm and screened to remove any paper or other large items of waste. A magnet is then used to separate and remove any metals within the glass. Next, the glass is passed through a vacuum to remove any final pieces of paper and then a non ferrous metal separator to remove any aluminium or lead (Glass Recycling



Source: From Parfett (2002)

Figure 2.
Glass waste destination

UK, 2007). The glass is finally crushed into fine glass particles which is utilised for the purpose of this research. The physical and mechanical properties of glass cullet are very similar to sand as it is a hard, granular material with similar particle density (Concrete Technology Unit, 2004).

The crushed demolition waste as used in the research was sourced locally after being run through a crushing machine producing a maximum aggregate size of 25mm and including all smaller subsequent sizes down to fine dust made up of brick, concrete and mortar. BRMCA (2008) suggest when the proportion of recycled aggregates exceeds 30 per cent of the primary coarse aggregate, the strength of the concrete reduces.

The supply of glass and demolition waste for re-use appears to be sufficient for future needs. The construction industry can be seen to take an active role in providing sustainable technologies for the future with the re-use of these materials.

3. Methodology and production

The manufacture of the concrete cubes involved the batching of three separate design mixes. The control mix produced four cubes batched, using virgin materials, in accordance with BS 1881. Part 103, 1983 and adopted CEM 1 OPC, coarse gravel (10-20 mm) and fine sand (0.5-2 mm) aggregates. The glass mix utilised glass cullett as a replacement for the sand proportion of the control mix producing a further four cubes. The recycled aggregate mix used in replacing the coarse aggregate fraction with recycled brick and aggregate and four cubes of this mix were formed. Each concrete was manufactured as a separate batch using a rotary drum mixer, and the cube compaction was carried out by hand in accordance with BS 1881: Part, 108:1983.

To ensure mix consistency BS EN 12350-2, 2000 was used to determine slump. The workability of a concrete mix increases with the increase of water content and the slump increases. The average slump was 50mm although the water cement ratios varied, 0.55 for plain concrete, 0.6 for glass concrete and 0.8 for concrete with demolition waste. Figure 3 illustrates the mix design employed in the test methodology.

After cube formation, the concretes were left to cure for 28 days within a 20^{8}C constant-temperature water-tank, in accordance with BS EN 12390-3, 2002.

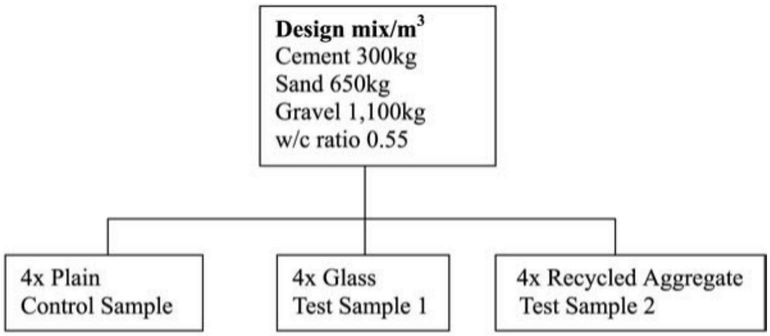


Figure 3.
Mix design

4. Results

The aggregates were mechanically sieved in accordance with BS 812: Part 103, 1985 and the results are shown in Figures 4 and 5.

The natural gravel coarse aggregate had a single sized grading profile, whereas the recycled aggregate was more evenly graded (Figure 4). Comparing the aggregate grading of the control sample to the glass aggregate, the grading profile shows a greater percentage of larger particles attributable to the sand within the control mix. Conversely the glass had a greater percentage of finer particles. The percentage passing the 600 micron sieve was 54 per cent for glass and 65 per cent for sand. An additional 10 per cent glass was added to the glass aggregate addition to compensate for the difference in particles passing the sieve in accordance with (Marsh, 1988) but no additional cement was introduced into the mix design.

Compressive strength tests were carried out to BS EN 12390–3, 2002 and the mean value of the test results carried out on each of the four cubes, of each of the three design mixes are shown in Figure 6.

When compared to the control batch, the recycled aggregate concrete shows a reduction in strength of 53 per cent and the glass used as a sand replacement shows a reduction in strength of 23 per cent. All cubes exhibited normal failure, however the glass particles showed a tendency for pull out failure due to poor bond between the glass and the cement hydrates (see Figure 7)

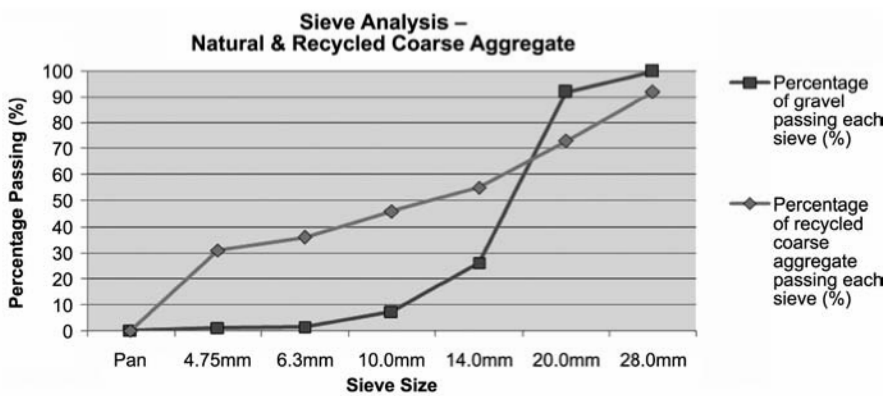
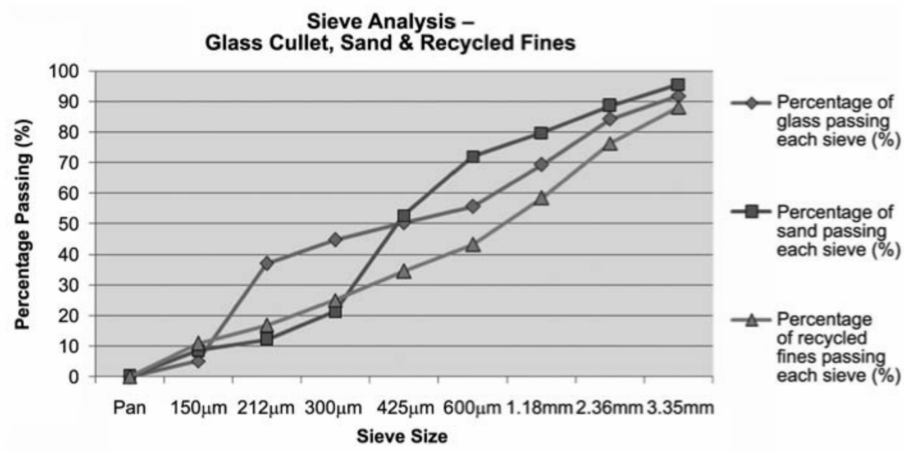


Figure 4.
Comparison of natural and recycled coarse aggregate



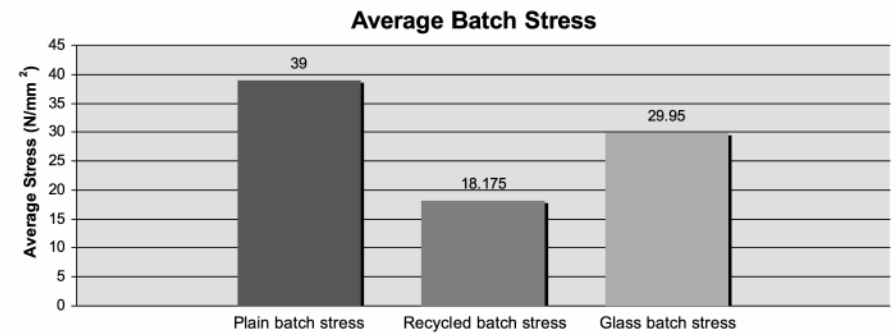


Figure 8 shows the relative density for each concrete type. Recycled aggregate concrete has the lowest density being 9 per cent less dense than plain concrete. The concrete with the crushed glass aggregate is 3 per cent less dense than plain concrete. The lower density can be attributed to the additional water required to achieve similar slump results to the glass and plain concrete mixes.

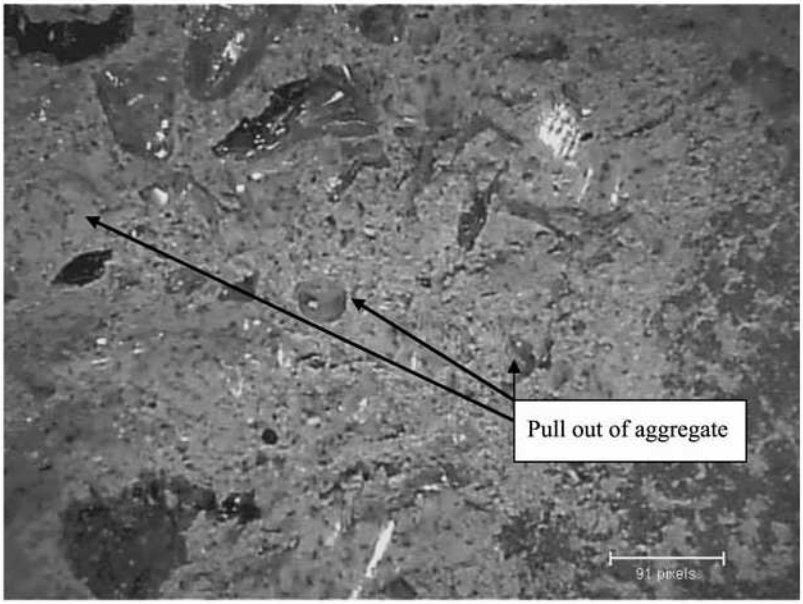
The batch densities obtained may have been predicted from water/cement ratios given in section 4 and conform to the findings of Poon *et al.* (2008) outlined in section 1. which highlighted the potential need for greater amount of water addition in the batching process, due to excessive fines and porous aggregates.

Conclusion

The lower concrete density (Figure 8) for the sand and recycled aggregates is indicative of poor particle packing and this is reflected with the final average compressive strength. It is recommended that if glass is used as a sand replacement, the supplier grades the crushed glass to an appropriate particle size and percentages prior to batching to accommodate needs of the required mix design.

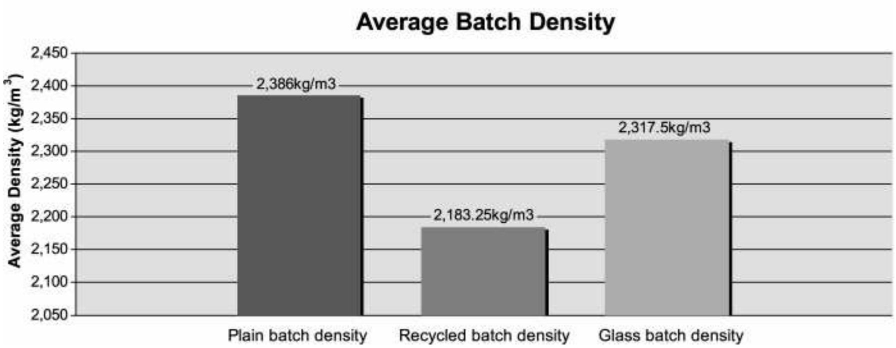
The low average compressive strength recorded for the recycled aggregate concrete was due to a higher water cement ratio; which was required to facilitate mixing due to

Figure 7.
Detail of glass aggregate showing pull out failure of glass particles



Note: Detail of glass aggregate showing pull out failure of glass particles

Figure 8.
Average density



the absorption of the recycled fine particles. Poon *et al.* (2008) corroborate these findings within their work.

It is concluded that un-graded crushed glass cullet and un-graded recycled construction aggregates are not suitable without pre-grading and treatment due to their high variability, however according to Dyer (2008) and (Poon *et al.*, 2008) satisfactory compressive strength results can be achieved when the design mix is carefully controlled.

Research limitations and further recommendations

The sample size was limited to four cubes of each type of concrete. The results would be more representative of a natural distribution if the sample size was increased. As work has been extensively carried out at the Concrete Technology Unit (2004) with regard to glass cullet used as a sand replacement, it was not considered necessary to continue the tests and replicate their work by improving the design mix using graded balanced design mixes; as this work is investigating the ungraded use of aggregate replacements. The effects of alkali silica reaction were ignored as this is generally found to be a problem when finely powdered glass is used. Suitable analytical techniques available to the researcher to establish the exact make up of the waste are – X-ray fluorescence, soluble ions, semi-quantitative X-ray diffraction, thermogravimetric analysis and hydrochloric acid selective dissolution. These combined analytical techniques allow for the estimation of the amount of cement paste, in its most important hydrated and carbonated phases, as well as the amount of clay and micas present within the waste (Angulo *et al*., 2009). The recycled aggregate may contain silt particles, therefore a simple silt test should be completed for all recycled aggregates. A simple silt test will act as an easy control measure. If it is determined that there is a large percentage of silt present then the aggregate is not suitable for concrete construction unless cleaned using screens or tumblers.

References

Angulo, S.C., Ulsen, C., John, V.M., Kahn, H. and Cincotto, M.A. (2009), "Chemical-mineralogical characterization of C&D waste recycled aggregates", *Waste Management*, Vol. 29 No. 2, pp. 721-30.

British Ready-Mixed Concrete Association (BRMCA) (2008), *Guidance Document on Sustainable Concrete Design and Rating Systems*, British Ready-Mixed Concrete Association, London.

BS 812: Part 103 (1985), *Sampling and Grading of Aggregate*, British Standards Institute, London.

BS 1881: Part 108 (1983), *Making Test Cubes*, British Standards Institute, London.

BS EN 12350-2 (2000), *Testing Fresh Concrete – Part 2. Slump Test*, British Standards Institute, London.

BS EN 12390-3 (2002), *Compressive Strength of Test Cubes*, British Standards Institute, London.

Byars, W.A., Morales-Hernandez, B. and Ying, Z.H. (2004), "Waste glass as concrete aggregate and pozzolan", *Concrete*, Vol. 38, January.

Collins, J. (1994), "The use of recycled aggregates in concrete", information paper, BRE, Watford, p. 02.

Concrete Technology Unit (2004), "Realising a high value sustainable recycling solution to the glass cullet surplus". Project spotlight, University of Dundee, Dundee.

Dyer, T. (2008), communication, Dundee University, Dundee.

Friends of the Earth, Durham (2004), available at: www.durhamfoe.org.uk/facts-and-figures/ waste/

Glass, J. (2001), *Ecoconcrete*, British Cement Association, London, p. 17.

Glass Recycling UK (2007), "Glass recycling process", available at: www.glassrecycle.co.uk/ prod1.asp?ID 1/4 274 (accessed 2 February 2008).

Hughes, D., Basheer, P., Elliot, T. and Hackett, A. (2004), "Use of building demolition waste as aggregate in concrete", Queens University, Belfast, available at: www.qub.ac.uk/civeng/ research/Intro/research_areas/waste/DemolitionWaste.htm (accessed 21 November 2007).

Marsh, D. (1988), *Design of Normal Concrete Mixes*, 2nd ed., BRE, Watford.

Otaka, F. (2000), "The state of using by-products in concrete", technical report, JIS, p. 04.

Poon, C.S., Lam, C.S., Kou, S.C. and Chan, D. (2008), "Recycling of construction and demolition waste and crushed glass cullet as construction materials, role for concrete in global development", Proceedings of the International Conference at the University of Dundee, UK, 8-9 July.

Sagoe, K. and Brown, T. (2002), "Durability and performance characteristics of recycled aggregate concrete" paper 090, CSIRO Publishing, UK.

WRAP (2007), "Realising the value of recovered glass", Recycled Glass Market Situation Report, January, available at: www.wrap.org.uk (accessed 15 December 2008).

Further reading

Parfitt, J. (2002), "Waste and resources action programme", available at: www.wasteonline.org.uk/resources/InformationSheets/Glass.htm (accessed 15 November 2007).