Towards A Safe and Sustainable Concrete Solution

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ABSTRACT: Concrete is considered to be a prime construction material in most parts of the world, well known for its contribution to the quality of construction, e.g. economy of construction, benefits to the environment through low energy demand in making concrete, saving of energy during the service life of the building afforded by its inherent insulation properties, etc. Such contribution of concrete construction could be enhanced further in the long term through research and development in certain areas. For example, there is a limit on the availability of natural minerals used for making cement and producing aggregates and it is important to investigate use of alternative sources for the constituents of concrete. In the long term, rapid depletion of natural resources would contravene the principles of sustainable development. There must be a prudent use of natural resources, so that the needs of the present can be met without compromising the ability of the future generations to meet their own needs. Solutions to this problem are sought through research on binders using optimum combination of cement and industrial by-products and also on recycling of concrete to produce aggregates for use in new construction. However, it is important to ensure that the use of any industrial by-product will not jeopardise quality of construction. This paper draws attention to some issues associated with the use of alternative sources for the constituents of concrete.

1 MERITS OF SUSTAINABLE CONSTRUCTION

At the 2002 UN World Summit on Sustainable Development, the participating governments recognised the importance of industry's contribution to sustainable development and pledged to enhance corporate environmental and social responsibility and accountability. Many industries in the UK are participating in voluntary reporting on sustainability under the auspices of "Global Reporting Initiative", a worldwide non-profit organisation that has a set of comprehensive sustainability disclosure standards. The UK Government has demonstrated its support to sustainable construction and sponsored many research projects concerning environmental issues, e.g. reduction in waste, use of industrial by-products, recycling of products of demolition, etc.

Sustainable construction represents a move away from the 19th century Industrial Revolution’s linear processes that result in inefficient conversion of energy and materials into a limited product with much waste. The move should lead us towards a ‘cyclical’ process for the 21st Century where much is recycled for reused. **[1]** This is a shift in thinking from linear, essentially ‘physics’ based processes, towards non-linear complex ‘biological’ based systems, using the advantages of modern technology coupled to a major behavioral change of the users of natural resources. Such considerations produce the 4Rs cycle – Reduce, Refurbish, Reuse and Recycle – a cycle echoing biological processes. If this cycle is adopted, it will benefit the planet by promotion of following considerations that apply to concrete construction:

– Reduction in emission of greenhouse gases during the manufacture of products.

– Standardisation of formwork and temporary works designs to allow for reuse.

– Focus on design loads to be just adequate for proposed use (including seismic, typhoon and groundwater effects), i.e. without any over-design of structure.

– Assessment of implications of design life (remembering that design life is theoretical, service life is a reality).

– Choosing structural components capable of being reused or recycled elsewhere.

– Investigation of possibilities of structural determinacy to simplify fabrication and future reuse as against the economies from structural redundancy and continuity.

– Where appropriate, incorporation of recycled materials and reused elements into new build.

– Choosing the structural system with an eye to low initial cost and reasonable embodied energy.

– Consideration of structural adaptability for future use and adequacy for alternative uses.

– Making sure that calculations and as-built records are available to facilitate reuse and adaptation.

– Keeping as-built documents to become part of requirements of ownership for efficient demolition.

– Use prefabrication to reduce waste on site and to recycle waste in manufacture at source.

– Design of joints for dismantling, demolition and reuse as well as ease of construction assembly.

– Demand on builders to produce an environmental and waste management statement with tenders.

2. CURRENT INITIATIVES IN THE FIELD OF SUSTAINABLE CONSTRUCTION

The current thinking generally stems from the basic issue of sourcing and processing of materials. For steel, a primary product, this process starts with extraction of iron ore and leads to manufacture of steel and its transportation for use in construction. Finally, subsequent reuse or recycling is achieved through the scrap recovery route. For concrete, which is a composite product, there is an issue of sourcing the raw materials – aggregates and limestone (for manufacturing cement in particular). In the UK, suitable sources are limited and often located in areas of outstanding natural beauty, making extraction of aggregate very detrimental to the environment. Furthermore, some 2% of the UK carbon dioxide emission is attributable to cement manufacture, which suggests that concrete contributes to the UK carbon dioxide emission to the extent of about 0.35%.

All these circumstances have led to increasing interest in using recycled materials and cement replacements. A small number of projects have been developed using recycled aggregate concrete. At the same time, many other industrial byproducts are being considered for recycling, e.g. glass, rubber tyres, incinerator ash, etc. However, there are difficulties associated with the supply of suitable material for reprocessing and potential reduction in quality of construction owing to lack of detailed guidance. These factors tend to discourage widespread implementation of recycled aggregate.

Sustainable building construction requires an urgent change in the way buildings are constructed and maintained, coupled with an awareness that we must avoid mistakes of the disastrous 1960s building boom in the UK. The Sustainable Buildings Task Group would address this issue, formulate a report and deliver it to the UK Government. This Group comprises leading building experts, both practitioners and academics, and it has been supported by the relevant UK Government Departments concerned with economy and efficiency of the construction industry, environmental improvement, regulations for health and safety, etc.

Reviewing the available technologies for environmental improvement, the Sustainable Buildings Task Group concluded that a significant uplift in quality is both possible and affordable. Its report calls for the Government and the building industry to adopt a single national Code for Sustainable Building, which would raise the quality standards and reduce the unsustainable use of natural resources in the built environment. The Group would wish to see development of such a code that could afford a consistent approach towards making today's buildings fit for the future. The new Code would incorporate standards that are above the minimum requirements of the Building Regulations, in the fields of waste management and efficient use of energy and water. The Group recommends that Government should lead by example and adopt these standards for all new buildings in the Public Sector. The Group also calls for tighter regulations to be enforced, so that all new buildings would reduce energy and water consumption by 25%.

It is envisaged that 10% of materials used in the construction of new buildings would be recycled or reused and more sustainable sources of materials would be encouraged. Waste would be better managed during construction and buildings would be designed for households to implement disposal of waste more effectively. It is believed that the construction, development and house building industries can subscribe much better to the sustainability agenda and that they need to be persuaded of the long-term benefits. The Code for Sustainable Buildings would provide them with a level playing field for quality buildings.

3. RECYCLED CONCRETE AGGREGATE (RCA)

Recycling concrete aggregate is important for reducing demand on primary sources of natural aggregate and for easing the pressure on sites for disposal of products of demolition. At present, RCA use is limited mostly to road construction and plain concrete. Rapid disposal of waste from demolished concrete structures has tended to be the preferred practice of the UK construction industry. Production of RCA for use in structural work would require careful and systematic processing, grading and testing of aggregate, essential for ensuring its acceptability in structural concrete. However, costs of such operations are considered to be too high at present.

There is enough evidence to show that RCA can be used to replace some 30% of the coarse aggregate in some grades of concrete meant for less demanding performance, e.g. concrete suitable for drives and parking for dwellings, external paving, foundations in non-aggressive soils, blinding, kerb bedding, etc. **[2]** RCA can also be used in some concrete grades meant for internal reinforced concrete members. Further work may suggest that use of RCA concrete can be extended to higher grades of concrete. However, in such instances, a designer has to appreciate deficiencies of RCA concrete regarding workability and the problems presented in the form of harshness of the mix, together with porosity and inadequate durability of the hardened concrete. It would be most inappropriate to increase water content and the cement content (to maintain the water-cement ratio) for the purpose of overcoming these difficulties. Such measures would jeopardize the basic principles of sustainability. Addition of fly ash is understood to be a successful solution for overcoming some of the problems, provided that its compatibility with other concrete constituents is established.

Another important issue, related to identifying any potential hazard, would be the specification for testing the RCA. It should not be used in any significantly important structural concrete elements, unless it is chemically inert and without any inherited impurities and problems such as alkali-aggregate reaction or chloride attack. Experience at Kingston University has suggested that many issues with the use of RCA could be resolved if the producers could adopt a common practice of quality control in crushing and cleaning up their product. Furthermore, special design considerations may be required before indulging in any proposal to use RCA concrete in members sensitive to creep and shrinkage

4. RESEARCH AT KINGSTON UNIVERSITY

Kingston University has a long tradition of successful research in the field of sustainable construction. For example, a programme dedicated to development of new design approach for unreinforced concrete in domestic basements has been completed, complementing the work being undertaken into design of unreinforced masonry basements. This exercise should assist basement construction, resulting in energy saving and reducing demand on land for new construction.

Recent diversification of the research base has resulted in development of the Concrete and Masonry Research Group and the Sustainable Technology Research Centre of the Faculty of Engineering. One of the principal activities is investigation of feasibility of using re-cycled materials as aggregate in concrete. This work has led to procurement of two main sets of equipment:

– A specialist freeze-thaw chamber for use in the sustainability area of research
– Carbonation tanks to accelerate the effect of carbonation on concrete.

Additionally, microscopical investigations into the chemical nature of concrete are undertaken as well as the usual wet, dry and non-destructive tests on concrete.

The following concrete research projects are under way at present, on the subject of feasibility of using recycled materials as aggregate in new concrete:

4.1 R*CA concrete with ordinary portland cement (portland cement Class 42.5)*

This project has demonstrated the suitability of recycled aggregate for use in a range of concrete applications using portland cement, through laboratory research and field trials. This investigation included characterisation of aggregates and development of suitable concrete mixes containing a range of blends of natural and coarse Recycled Aggregate (RA) in trial mixes. Full-scale demonstrations were built with RA concrete and assessed, including a variety of structural and paving elements. These demonstrations are being monitored over the long term. In the meantime, there is enough evidence to show that RA could be used successfully in a range of concrete applications. The existing project output comprises technical papers and running of various workshops, including a technical skills workshop.

4.2 *RCA concrete with binary cements containing pulverised fly ash, silica fume and ground granulated blast furnace slag*

This project demonstrates the suitability of recycled aggregate in a range of applications using binary cements, thus enhancing the principle of sustainable construction further and combining the advantages of using recycled aggregate with using cement comprising industrial byproducts. The binary or blended cements represent combination of ordinary portland cement with fly ash, Silica Fume, and GGBS (ground granulated blast-furnace slag). The findings of this project endorse the guidance given in the new European Standards for concrete and aggregates, which allow the use of recycled aggregates and by-products such as fly ash, Silica fume and GGBS combined with ordinary portland cement.

4.2 *Other materials*

Kingston University has developed good contacts with the industry and made significant progress in the field of using glass, with manufacturing of globules that encapsulate crushed glass. Vehicle tyres are also cut very small and converted into aggregate that can be used in semi-flexible pavements, potentially in children's playground.

5 PRECAUTIONS WITH GGBS CONCRETE

It is a common experience that the hessian-cured cubes give strength that is about 90% of the water-cured cubes. However, for the low water-binder ratio mixes, particularly mixes containing GGBS, this difference can be very significant. While curing is beneficial to all concrete construction, it is most important for development of strength in GGBS concrete. The writer has reported tests on beams where air-cured cubes (placed by the side of test beams) were used to determine the compressive strength of beam concrete. **[3]** This was crosschecked with results of tests on water-cured cubes, which were noted to be about 10% higher for PC concrete but about 30% higher for GGBS concrete.

Tests carried out by Nakamura et al **[4]** on concrete specimens with GGBS have shown a similar trend and revealed some characteristics of such concrete associated with different curing methods. They concluded that air-curing without any water-curing could be a substantial impediment in development of strength. Irrespective of slag-fineness and water-binder ratio, 91 days strength of air-cured specimens was found to be only about 60 to 70% of 28 days control strength of water-cured specimens. They recommended that a minimum of six days water-curing would be required for slag concretes to reach strengths obtained by continuous water-curing. If such curing regimes were to be necessary for using slag concrete in buildings, its use may not be very practicable.

Concrete Society Technical Report 40 **[5]** comments on the effect of temperature during the early life on strength development of GGBS concrete. Exposure to modest thermal cycling is believed to have a beneficial effect but, for concrete with 70% GGBS, standard cured strength at 28 days is observed to be 32.5 N/mm^2 compared with 43.5 N/mm^2 for PC concrete with cement content of 300 kg/m^3. Further research is required to clarify such dependence on curing conditions, if GGBS concrete is to be used in common structures.

If GGBS concrete is used in any part of the building or a bridge connecting the car park and the building, a designer should record the explicit curing regime essential for achieving the expected performance of the structure, both from the point of view of strength development as well as that of the requisite durability.

6 A CASE STUDY EXAMPLE OF THE ROLE OF A CONSULTING ENGINEER

A leading UK consultant, Buro Happold, suggested the use of recycled aggregate (RCA) concrete for the project **"**Wessex Water New Operations Centre, Bath", and approved its use in works. **[6]** At the feasibility stage, the design team had undertaken careful studies to compare the environmental impact of various materials in terms of emissions, waste resources and future recycling. In addition to using RCA concrete, local Bath stone would be used to clad the street and some external areas, and stone excavated from the site would be used in the perimeter walls.

In the specifications, Buro Happold asked the tenderers to propose sustainable alternatives. These were evaluated in conjunction with their base bid and price. RCA concrete was suggested to the tenderers for the concrete structures package in this context. The successful tenderer was then asked to explore the viability of sustainable options and advise as to any additional initial capital cost. Wessex Water reviewed the proposals and accepted the one involving RCA concrete. Buro Happold engineers recognised that the viability of using RCA greatly depended on its being a clean local source. It had to be clean to reduce sorting costs and to give greater confidence in the product; the source had to be local to minimize the cost and environmental impacts associated with transportation (particularly by road). In this instance, prestressed concrete railway sleepers were used as source material for RCA. The sleepers were munched to remove prestressing wire and the aggregate was suitably cleaned and graded afterwards.

The additional initial capital cost of using RCA on this project represented approximately 5–6% of the cost of the placed concrete. The engineers had decided to limit the proportion of coarse aggregate replaced by RCA to 40%, to minimize any risks identified by suppliers, e.g. continuity of supply, and any possible risks to the client, such as concerns about effects on programme, ensuring freedom from long-term durability problems, etc.

7 CONCLUSIONS

It is imperative that engineers should respond to the challenges of sustainable construction and show increasing interest in using recycled materials and cement replacements. In addition to RCA, fly ash and GGBS, there are some other alternative materials obtained from industrial byproducts, e.g. glass, rubber tyres, incinerator ash, etc. However, there are difficulties associated with the supply of suitable material for reprocessing and potential reduction in quality of construction attributable to lack of detailed guidance. These factors may discourage widespread implementation of alternative constituents of concrete. However, the use of such materials should become more acceptable, with the producers adopting a common practice of quality control, e.g. in crushing and cleaning up the RCA, and with further research as described above and proper methodology used by engineers as described in the Wessex Water project.

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