PRECAST CONCRETE BUILDING BLOCKS MADE WITH AGGREGATES DERIVED FROM CONSTRUCTION AND DEMOLITION WASTE

Marios N. Soutsos (1), Nicola Jones (1), Stephen G. Millard (1), John H. Bungey (1), R Geoff Tickell (1), Jo Gradwell (2)

(1) Department of Civil Engineering, The University of Liverpool, Liverpool, UK
(2) Enviros Ltd, Manchester, UK

Abstract

The potential for using construction and demolition waste (C&DW) derived aggregate in the manufacture of precast concrete building blocks is currently being investigated at the University of Liverpool. A market research study has been carried out to determine the economic viability of using C&DW derived aggregates in the production of concrete building blocks. The availability and transportation costs of quarried and C&DW derived aggregates have been compared and there appears to be scope for investigating the technical aspects, in addition to the economic aspects, of the use of C&DW derived aggregates in the manufacture of building blocks. The manufacturing process used in factories for large-scale production involves a “vibro-compaction” casting procedure, using a relatively dry concrete mix with a low cement content (≈100 kg/m$^3$). Trials in the laboratory have replicated the manufacturing process by using a specially modified pneumatic hammer drill to compact the concrete into steel moulds to produce blocks with the same physical and mechanical properties as commercial blocks. It has been found in this study that the physical characteristics of C&DW aggregates adversely affect the mechanical properties of concrete blocks if coarse and fine aggregate replacement levels above 20% are used. If the compressive strength is to be maintained using C&DW derived aggregates at replacement level higher than 20% then the cement content must be increased, with a consequential impact on the cost advantage of using C&DW aggregate.

Keywords: Recycling, sustainability, construction and demolition waste, blocks, aggregate.

1. INTRODUCTION

In 1991 the European Commission initiated the Priority Waste Streams Programme for six waste streams. One of these streams is construction and demolition waste (C&DW) [1]. Concrete, bricks and tiles, are all well suited to being crushed and recycled as a substitute for newly quarried (primary) aggregates.

While C&DW accounts for 17% of the estimated annual waste in the UK [2], about 220 million tonnes of new construction aggregates are extracted annually. About 60% of this is crushed rock and 40% is sand and gravel [3]. These are essential materials for buildings and infrastructure, but extraction causes significant environmental damage. The UK government aims are to reduce demand for primary aggregates by minimising the waste of construction materials and maximising the use that is made of alternatives to primary aggregates [4]. An attempt to address the environmental costs associated with quarrying has been the introduction in the UK of the aggregates levy in April 2002 [3,5].
Although there are many potential uses for C&DW materials, the majority of materials are currently used for low-value purposes such as road sub-base construction, engineering fill, or landfill engineering. Only 4% is recycled for high specification applications. The reason for this is that while many C&DW materials could be used for higher level uses, potential users are deterred by the perceived risks involved [4]. There is therefore a need to increase confidence in the use of recycled materials, which can only be achieved by identifying, undertaking and monitoring appropriate demonstration projects, and disseminating the results through publications and seminars [5].

2 AIMS AND OBJECTIVES OF PROJECT.

The objective of this project is to investigate the use of crushed C&DW in the production of blockwork and other precast concrete units. In addition to investigating the technicalities of producing concrete using C&DW, the economics & practicalities involved are being investigated. The project has set up a quality network which encompasses demolition contractors, Waste Collection Authority (WCA) and Waste Disposal Authority (WDA) Councils and precast concrete product manufacturers. Specific aims are to develop definitive designs and specifications for the reuse of demolition waste for high quality building products. The extent to which a selection of high performance precast concrete products can be produced using building rubble as aggregate in place of natural raw materials is currently being investigated. The more traditional waste product additives of pulverised fuel ash (pfa) and ground granulated blast-furnace slag (ggbs) as cement replacements are also incorporated into the mix designs to maximise the use of recycled waste products.

3 PRODUCTION COSTS FOR BUILDING BLOCKS.

The common/standard block is a commodity product, costing between £0.30 and 0.35 per block in the UK, and therefore the profit margin is low. Most manufacturers also produce a speciality range of more expensive facing blocks or architectural masonry blocks. Nonetheless, the common block weighing approximately 20 kg continues to dominate sales, accounting for 7 of every 10 blocks sold. Transportation costs influence the location of precast factories; in the majority of cases the decision has been to have the precast factory close to or even at the quarry site. The common block is also only sold regionally; within a radius of 30 miles of the precast factory.

4 AVAILABILITY AND COST OF C&DW DERIVED AGGREGATES.

Liverpool has been selected as a realistic example to illustrate the capability of using C&DW derived aggregates in the production of building blocks. Liverpool Housing Action Trust (LHAT) alone is expected to demolish 56 out of the 72 tower blocks in Liverpool between 2001 and 2006. One of these tower blocks, Figure 1, that was demolished using explosives, a technique known as “implosion”, produced 15,000 tonnes of construction and demolition waste, Figure 2. The trucks transported this “waste” to a nearby crushing plant where it was converted to road sub-base material. The costs for crushing the C&DW, which is estimated to be approximately £7.22 per tonne, is not recovered when it is sold as road sub-base aggregate. The selling price depends heavily on the demand and can vary between £2.00 and £4.00 per tonne. The demolition contractors are still therefore required to cover the difference and they end up paying the recycling plant to take away the C&DW. Operators of crushing plants would also welcome not only an increase in price per tonne but also a guaranteed constant/regular demand for the C&DW derived aggregate. Block making factories appear to be very interested in C&DW derived aggregates if the price is lower than that of quarried aggregate. A conservative value of £7.00 per tonne for 6mm C&DW derived
Figure 1: The Kenley tower block minutes before it was demolished.

Figure 2: 15,000 tonnes of C&DW – Kenley tower block.
aggregates would satisfy both the operators of crushing plants as well as the block making factories. It is estimated that at least 500,000 tonnes of dense aggregate is consumed each year by precast concrete block manufacturers in the North West of England. At the same time, it is estimated that 4.5 million tonnes of hard C&DW is produced annually in the North West. There is therefore an opportunity to replace some of the virgin aggregate consumed in the North West with C&DW derived aggregates without unbalancing the existing markets for C&DW.

5 PHYSICAL PROPERTIES OF C&DW AGGREGATES.

If C&DW derived aggregates are to be used in the production of concrete blocks then the specific gravity, angularity, fineness, and water absorption are all important physical properties that need to be taken into consideration. All these properties will be affected by the source of C&DW. The C&DW from the demolition of tower blocks will, in the majority, be concrete, Figure 3. However, the next source of C&DW, once the demolition of the tower blocks is completed, will be residential council houses that are in the majority masonry buildings, Figure 4. The masonry-derived aggregates are expected to have more of a detrimental effect on the compressive strength of blocks than concrete-derived aggregates. It is because of this that masonry-derived aggregates have been selected to be used in this study first. The masonry-derived aggregate has very high water absorption (10.5% and 12.5% by

Figure 3: Typical precast concrete tower blocks that are currently being demolished.
weight for coarse and fine aggregate respectively, compared to 0.7% for coarse and 3.7% for fine quarried limestone aggregate). The high absorption of C&DW derived aggregates is similar to the behaviour of man-made lightweight aggregates. The mixing procedure adopted for making concrete using lightweight aggregates has been tried, i.e. pre-mixing of half the mix water with the aggregate, then adding the cement and the remaining water. Furthermore, because of the more irregular surface of crushed C&DW, the cement content is increased to fill the resulting micro-spaces. Cement is the most expensive component of precast concrete products, so this adds to the cost of using C&DW derived aggregates.

6 EXPERIMENTAL WORK.

Purpose built moulds were designed and fabricated in the workshop to enable a full height but half-length block specimens to be made, Figure 5. A “compaction rig” was designed and fabricated that allows the pneumatic hammer drill to slide down steel rods down to a pre-determined height, Figure 6. The moulds are oversized in height to allow the uncompacted material to be placed in them. The weight of wet material required to produce a concrete block of approximately 20 kg when dry, is estimated from previously determined wet/dry density relationships. The pneumatic hammer drill then compacts the material to the required height of 215 mm, the height of factory produced blocks.

The first series of tests was carried out, using the same mix proportions and materials as those used by a precast factory, in order to confirm that the above laboratory method replicated the factory production techniques. Rapid hardening Portland cement and limestone aggregates were obtained from Forticrete’s precast factory at Buxton. There were initially some difficulties in obtaining compressive strengths in the laboratory that were similar to those obtained by the factory. One of the critical parameters appears to be the density of concrete block. A range of acceptable densities, i.e. 1850 to 2050 kg, was provided by Forticrete Ltd. However, all the factory-supplied blocks were found to be at the upper limit of this range.
Figure 5. Laboratory moulds for block making.

Figure 6. Vibro-compaction rig.
An initial series of tests was carried out to investigate the relationship between compressive strength and density. Initially the density considered was the wet density of the block as soon as it was cast. Water loss during curing appears to be considerable. Wet density relationships with compressive strength were determined, Figure 7. Lower strengths obtained in the laboratory (5 MPa compared to 7 MPa) proved to be due to aiming for blocks with a wet density of 1925 kg/m$^3$ instead of a dry density of 1925 kg/m$^3$. This dry density was also found to be on the low side compared to the densities of blocks obtained from Forticrete Ltd. The target dry density was therefore increased to 2000 kg/m$^3$ and this has been found to correspond to a wet density of 2050 kg/m$^3$. Once blocks were made in the laboratory with a wet density of 2050 kg/m$^3$ there was no further difficulty in achieving the target strength of 7 MPa.

Concrete and masonry derived aggregates were obtained from DSM Demolition Ltd and crushed by W F Doyle Ltd. The lower density of 100% masonry derived aggregate has forced consideration of replacement of quarried aggregate on a volume basis rather than on a weight basis. The wet density of masonry-derived aggregate blocks has been found to be between 1650 to 1800 kg compared to 2050kg for limestone aggregate. Strengths were therefore adversely affected by (a) the higher water-cement ratios required to obtain a well compacted block, and, (b) the reduction in the density of the blocks, because of the lower density of masonry derived aggregates.

The increase in the cement required to maintain the strength at 7 MPa when the coarse quarried aggregates, i.e. 5mm, are replaced by masonry derived aggregates was found to be approximately 70 kg/m$^3$, see Figure 8, which would have added between 10 and 15% to the cost of the block. This is unacceptable under the current market. However, Figure 9 shows that the coarse fraction of the aggregate can be replaced by up to approximately 20% with masonry derived aggregates without having any detrimental effect on the compressive strength.

Figure 7: 28-day strength versus wet and dry densities.
Figure 8: Cement content required for 7 MPa when the coarse limestone aggregate, i.e. 5 mm, is replaced by masonry derived aggregate.

Figure 9: Compressive strength as affected by replacement of coarse fraction of limestone aggregate with masonry-derived aggregates.
7 CONCLUSIONS.

The location of aggregate resources may encourage the use of C&DW derived aggregates in certain areas. It is believed that Liverpool, whose regeneration calls for demolition and major reconstruction, can benefit from a high value end use of C&DW derived aggregates. The market research carried out has shown that most of the 4.5 million tonnes of C&DW annual arisings are crushed and/or screened for use as aggregate, mainly for low value road sub-base use. However, the costs associated with crushing the C&DW are not recovered and there is therefore scope for investigating a high end value market, such as their use in concrete building blocks. Technical aspects of the production of blocks need also be incorporated into the cost model. The physical properties of C&DW aggregates affect adversely the mechanical properties of the blocks. If the strength is to be maintained then the cement content needs to be increased in respect to blocks made with quarried aggregates. Experiments have shown that the coarse fraction of the aggregate can be replaced by up to approximately 20% with masonry-derived aggregates without significantly affecting the compressive strength.

ACKNOWLEDGEMENTS.

The authors are grateful to the ONYX Environmental Trust and the Flintshire Community Trust Ltd (AD Waste Ltd) for funding this project. The authors would also like to thank the following industrial collaborators for their assistance with the project: Clean Merseyside Centre, Marshalls Ltd, Forticrete Ltd, Liverpool City Council, Liverpool Housing Action Trust (LHAT), RMC Readymix Ltd, WF Doyle & Co. Ltd, DSM Demolition Ltd., and Environmental Advisory Service – Merseyside.

REFERENCES