NON-TRADITIONAL BINDERS FOR CONSTRUCTION MATERIALS

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Abstract

This paper confirms the potential for a construction material composed of 100% recycled by-products; a ten-fold increase in the amount of waste material currently able to be utilised in similar conventional construction materials. This is made possible by the use of alternative binders such as waste bitumen instead of traditional cementitious or clay binders. Seven main waste materials are considered: steel slag; crushed glass; pulverised fuel ash (PFA); incinerator bottom ash (IBA), incinerated sewage sludge ash (ISSA); rice husk ash (RHA); and eggshells. The new materials have been manufactured in construction block form. Several properties of the new units have been measured and shown to compare favourably with those of current concrete aggregate blocks.

Introduction

Recent legislation [1-4] introduced by the UK government in response to a number of EU directives will result in further quantities of materials being recycled and also new types of recycled materials being generated. There is already an excess of certain types of recycled material – currently these materials are either stored or sent to landfill. Also, this increase in recycling will result in excesses developing in recycled materials which currently have a market. The introduction of the Landfill Directive (1999/31/EC) and the Landfill (England and Wales) Regulations 2005 will also increase the amount of recycled material available. This legislation has made it more difficult to dispose of waste by this route and means that it is becoming increasingly more expensive both in terms of the cost to use the landfill and the additional pre-treatment that is now demanded before it can be sent to landfill. New products are therefore required to make use of these excess waste materials.

The construction industry has made attempts to utilise these waste materials and in doing so enhance its reputation and its perceived attitude on sustainability by the government and the public. Highways have been particularly successful in utilising secondary materials without compromising the technical requirements of the product. However, it is becoming increasingly more difficult to achieve this as there is continuous pressure to increase the levels of replacement and utilise lower quality material. In buildings and structures infrastructure many types of wastes are used as replacements for traditional aggregates and binders in cementitious and clay bound materials as well as flux materials and fuel in the different manufacturing processes. Whilst this is a positive approach and a certain degree of success has been achieved, it is becoming clear that construction materials using current binders will not provide a satisfactory route for recycling these waste materials. The effect on the performance of the materials is significant and unacceptable if in many cases more than 10% of recycled material is incorporated. The effects can be reduced, but this often means a significant increase in binder (i.e. cement) content.

There is an opportunity here for the construction industry. However, in order to grasp this opportunity it needs to consider the use of alternative binders. This paper summarises the development of a number of innovative new construction materials which use waste bitumen and waste vegetable oil or as binders to produce materials with a range of properties which are expected to be suitable for a number of construction applications.

The research has set out to achieve four major objectives. These are to:-

- Reduce primary extraction
- Reduce CO_2 emissions
- Allow the significant use of waste aggregates
- Allow the use / disposal of 'Hazardous' materials (i.e. waste bitumens and cooking oils)

The novel materials discussed here are composed of 100% recycled waste material / aggregate - a ten-fold increase in the amount of waste material currently able to be utilised in similar conventional construction materials.

Manufacturing methods and their implications on the development of the materials

It is appreciated that the development of these innovative new materials using non-traditional binders will require a step-change in the current manufacturing processes. From the outset it was therefore decided that this development process had to proceed from both an academic and commercial perspective i.e. achieve confirmation that the methods would work whilst considering suitability to current industrial processes to assist with ease of manufacture.

This approach has not always been successful. Implementation of any innovation is difficult especially in a cost driven industry. This difficulty is compounded where markets are controlled by a small number of major organisations. This is further compounded when cost savings for utilising recycled materials, a primary benefit of these new products presented here, is undermined by the legislative approach to cost rewards offered currently by the government. It was initially believed that if comparable production costs to conventional materials could be achieved then the attraction for these new products would be the avoidance of landfill tax and primary aggregate extraction tax and the cost rewards for using recycled materials. It was still expected that this would be the case should the new production costs exceed current manufacturing costs. Unfortunately, the current government reward system, which is under review, has effectively reduced the value of using many waste aggregates to zero. (It is expected that there are a number of reasons for this. One in particular may be that as soon as you give a recycled material a market, the material will have a value attached to it and a charge can be made for the supply of that material!). At this point in time the research is identifying waste streams which have a high value (or purchase recovery note (PRN)) attached to them. Fortunately, another of the benefits of these new binders is that they are highly versatile and can accommodate most recycled materials in various combinations.

In this paper, two new materials have been used to manufacture a building unit and the properties of these new products and the processes used in the manufacture are compared with those of traditional concrete aggregate building blocks.

Briefly, the manufacture of concrete blocks consists of several stages; mechanical mixing of materials at ambient temperatures; compaction; and then curing for up to 24 hours at around 75 °C.

'Bitublock'

A penetration grade bitumen was tested as a binder for manufacturing the building blocks and the quantity of bitumen was optimised to match the content of cement in aggregate blocks (6%). Initially, a 50 pen grade bitumen with well known rheological properties which is commonly used in road construction and is readily available was used. To facilitate mixing of the materials, heating of both the bitumen and the aggregates is required prior to and during the mixing of the materials. This was to reduce the viscosity of the bitumen (target approx. 0.2 Pa.s) so that it is highly 'flowable' and to ensure that the aggregates were hot enough so as not to cool the bitumen when they came into contact with each other (target temperature typically 160 °C) [5-7].

The hot bituminous mixture was then cast in moulds and compacted. The properties of the block at this stage in terms of compressive strength were equivalent to those of concrete blocks (typically the compressive strength of concrete blocks is in the range of 3 to 7 MPa). However, due to the viscous nature of bitumen the blocks possessed large deformations under the creep loading levels that may be sustained by building blocks. Further heating (a curing regime of 200 °C for 24 hours) was required to fully oxidise the bitumen (converting it from a visco-elastic to an elastic-brittle material) to produce a dimensionally stable block. At this stage the properties of the cured block, even when containing 100% recycled aggregate material, are much better than that of standard concrete blocks and are equivalent to class B / C clay bricks (which are fired at around 1000 to 1300 degrees C for up to 20 to 24 hours). A range of waste/recycled aggregates were successfully utilised in the Bitublock manufacturing process including incinerated bottom ash (IBA), steel slag, crushed glass, fly ash (PFA), incinerated sewage sludge ash (ISSA), rice husk ash (RHA) and eggshells.

It was clear nonetheless that in terms of heat input during the manufacturing process this method of manufacturing did not compare well with the current process for concrete blocks (and also meant that existing block manufacturing equipment could not be used). In an attempt to reduce the intensity or duration of the curing regime, a range of hard and oxidised industrial grade bitumens were tested. However, it was found that the curing regime could not be significantly reduced. Interestingly, a waste bitumen (one that oxidises very quickly, has no current value and has to be landfilled as a 'hazardous' material) has been found to be suitable for the Bitublock process and this is envisaged to help enhance the cost comparison between bitumen and cement which is approximately 2 to 1 for conventional bitumen.

From the research conducted so far it is clear that Bitublock cannot be made using current concrete block making equipment. A modified system would have to be developed which allows the Bitublocks to be cured at temperatures in excess of what is currently used for concrete block manufacture.

The successful use of incinerated bottom ash (IBA) from municipal waste incinerators in Bitublock is highly beneficial. It is therefore envisaged that a Bitublock manufacturing plant could be established adjacent to an existing or future incinerator, and a small amount of the excess heat from the incinerator could be diverted to assist with heating during the mixing and curing stages after compaction. Additionally, by locating the block manufacturing plant next to an incinerator, the cost of transporting the aggregates would be significantly reduced.

Modified 'Bitublock'

One of the key objections to the Bitublock process was the requirement for pre-heating the aggregates and binder to an elevated temperature to acquire adequate workability for mixing and compaction. In order to reduce the energy input at this pre-heating stage, it was decided to investigate ways of reducing the viscosity of the bitumen so that it becomes a workable binder at ambient temperature and remains so even when in contact with aggregates. This is still being investigated.

'Vegeblock'

Bitublock limitations include the initial heat energy required during the mixing and compaction stages and the level of temperature required during the curing stage. Although the step of pre-heating the mineral aggregates is potentially eliminated by using a blended bitumen binder, nonetheless, one other problem remained which was the colour of the finished product. Due to the bituminous component of the binder, all blocks are predominantly dark brown / black in colour (see Figure 4 and 5), which is not always the preferred colour for wall construction (however, this 'ash' colour is popular for other construction materials).

It was therefore decided to further investigate non-traditional binders and it was found that waste vegetable oil can easily be mixed with recycled aggregates at ambient temperatures to produce a very workable, easily compactable product named Vegeblock. The visual appearance of Vegeblocks is highly attractive in that the units reflect the colour of the aggregates used in the manufacturing process (see Figure 1).

Figure 1. Examples of Vegeblock

Once again curing is required to fully oxidise the vegetable oil and hence stabilise the block. However, due to totally different chemical composition of vegetable oils as opposed to bitumens (mineral oil derivatives), the curing regime was far shorter [8]. Typically curing a Vegeblock only consists of heating for 12 to 24 hours at 120 to 160 °C (curing at higher temperatures appears to be detrimental to the strength property of the block – see Figure 2 and 3). The properties of the Vegeblock are once again at least equivalent to concrete blocks.

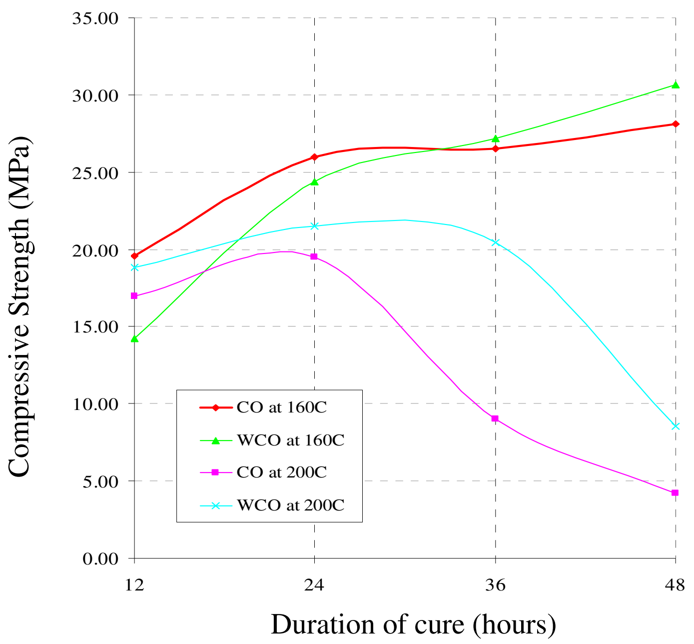

Figure 2. Effect of cure duration and temperature on compressive strength

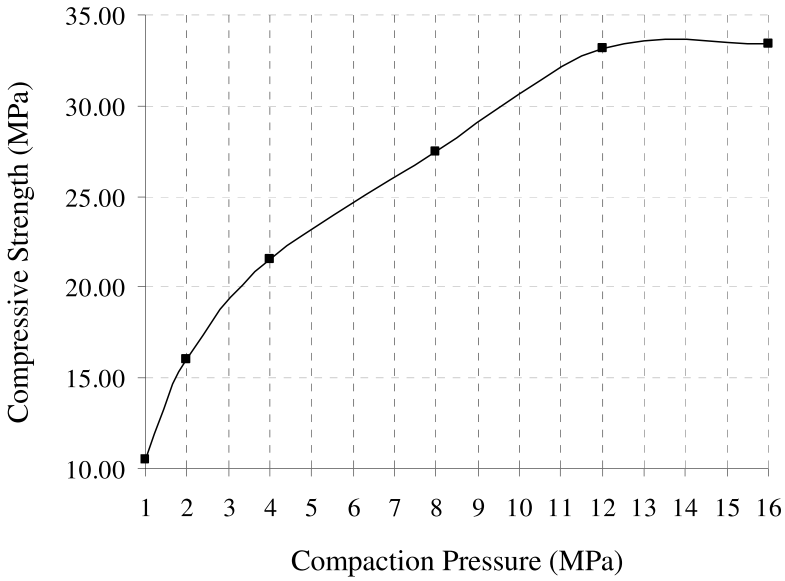

Figure 3. Effect of compaction level on compressive strength

Summary of Properties of Bitublock and Vegeblock

Table 1 illustrates typical proportions of each of the recycled materials that have so far been found to be suitable for the manufacture of Bitublock and Vegeblock units. The quantities and particle sizes of the recycled aggregates are limited by their flakiness, crushing values, absorption properties and ability to be fully coated by the binders. The table also indicates the range of compressive strengths of the blocks that can be obtained for these proportions of recycled materials.

	Steel Slag	Crushed Glass	IBA	PFA	ISSA	RHA	Eggshells	Compressive Strength range (MPa)
Bitublock	25-58	15-50	12.5-90	4-12	5-100	10	-	4 to 50
Vegeblock	8-49	6-48	-	7	6	-	100	4 to 33

Table 1. Typical proportions of recycled materials and compressive strengths

Bitublock units have been combined with a class (iii) cement / sand mortar to construct a wall (Figures 4 and 5). It is the intention to develop a recycled bitumen based mortar. However, this exercise was carried out to determine whether or not Bitublock can be combined with a traditional cement mortar. It was concluded that it was easier to build with Bitublock than with a class 'A' engineering brick. (The water absorption properties of Bitublock are sufficient to allow bonding of the unit and mortar during construction.) In addition, reduced mortar joints (5 to 8mm) were possible because of the regularity of the Bitublock sample. Figure 4 is an example of a 'cleaned' wall. Figure 5 illustrates an as-built wall where it is clear that mortar contamination of the Bitublock units in the wall has occurred and, if left un-cleaned is clearly detrimental to the appearance of the wall. The use of Bitublock as a facing unit is therefore debatable from an aesthetic perspective.

Figure 4. Bitublock Wall

Figure 5. Bitublock Wall (un-cleaned)

Conclusions

The extraction of primary aggregates can be reduced by the introduction of a construction unit which can be manufactured to incorporate 100% recycled material. (This could significantly reduce the amount of material currently disposed of to land-fills.) These new units possess properties which are at least equivalent to current concrete blocks.

A unit can be introduced which uses waste bitumen as the binder. As a consequence this will reduce the amount of hazardous waste sent to land-fill.

These new units will provide a potential product for new / increased waste streams.

Whilst not quantified, in terms of replacing the cement binder used in block manufacture and other applications, the use of these new materials should have a positive effect on the reduction of CO_2 emissions.

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