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X-ray computed tomography and fractal analysis for the evaluation of segregation resistance, strength response and accelerated corrosion behaviour of self-compacting lightweight concrete

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HIGHLIGHTS

- Fractal characterisation and X-ray CT analysis of self-compacting lightweight concrete are carried out.
- First study to analyse the segregation of concrete by means of 3D X-ray CT accompanied by image analysis.
- Fractal dimension and fracture energy increase with the increase of the complexity of corrosion morphology.
- Inherent void distribution is the dominant factor determining strength performance.

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ABSTRACT

In this study, fractal analysis and 3D X-ray computed tomography accompanied by digital image analysis technique are used for the quantitative evaluation of segregation resistance, static strength and corrosion-induced cracking in normal self-compacting concrete and self-compacting lightweight concrete. From image analysis performed on the vertical sections of the specimens, it was observed that self-compacting lightweight concrete had much higher resistance to segregation and the use of coarse lightweight particles in self-compacting concrete did not contribute to extensive level of anisotropy. The results also indicate that self-compacting lightweight concrete was weaker in compression than normal self-compacting concrete mainly due to less homogeneous internal structure. Finally, it was also shown that self-compacting lightweight concrete had lower susceptibility to corrosion in the early stage of exposure to the chloride environment than normal self-compacting concrete and greater fractal energies were dissipated in self-compacting concrete made with less porous and stiffer conventional aggregates.

1. Introduction

Self consolidating concrete (SCC) is a new class of high performance concrete characterised by the high fluidity under its own weight so that it can be placed without mechanical consolidation, easily fill small interstices of formwork and be pumped through long distances [1]. As a common practice, SCC contains a large volume of powders apart from the traditional concrete constituents (such as sand, coarse aggregate, water and admixtures) and thus its density is much higher than that of conventional concrete [2] leading to an increase in the dimension of load-carrying elements and consequent foundations loads. Ideally, employing lightweight aggregates in SCC cannot only overcome the aforementioned problem but also combine the favourable properties of lightweight concrete and SCC. Lightweight concrete can decrease the dead weight of structure which can result in reduced seismic force in a structure building [3]. On other hand, SCC can prevent the segregation of lightweight aggregates and produce a lightweight concrete with enhanced quality and higher compressive strength [4].

As a practical concern, self-consolidating lightweight concrete (SCLC) is a possible candidate for use in long-span bridges and reinforced concrete constructions built in marine and coastal areas. Under such circumstances, the concrete are most likely to be under the threat of chloride initiated corrosion [5,6]. Therefore, it is very important to assess the corrosion performance of such concretes apart from strength and workability. It would not be

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an exaggeration to say that chloride-induced reinforcement corrosion is today one of greatest challenges for scientists on concrete technology. Considerable research activity is still going onto have a look behind the curtain. But this does not mean that our knowledge is scarce on that area. At that point, the beginning question should be what drives the corrosion damage of cementitious materials when exposed to chloride solutions and how this in turn affects the properties of concrete at the macro-scale. Corrosion of steel in reinforced concrete is essentially an electrochemical process that leads to the dissolution of iron to form a range of solid products, which are a complex mixture of iron oxides, hydroxides and hydrated oxides [7]. The corrosion of steel takes place as a result of either the reduction in alkalinity (pH) at the steel, due to carbonation of concrete or leaching of alkalis, or the presence of a significant amount of chloride ions in the concrete [8]. Reinforcement corrosion reduces the cross-sectional area of the rebar, thereby, diminishing its load-bearing capacity and degrades the integrity of the surrounding concrete [9] and thus triggers off a catastrophic failure.

One of the most important micro-structural characteristics of concrete is its distinctive pore structure associated with a large number of pores with different sizes, shapes and origins. Today the researchers have accepted the common view that the pore structure of concrete controls its physical, mechanical and durability properties. The permeability of concrete is strongly influenced by connectivity of pores, while the compressive strength is primarily affected by the total volume of pores [10]. Similarly, durability to freezing and thawing and de-icer scaling are primarily governed by the volume and spacing of entrained air voids [11]. Thus, the study of pore structure should assist in a more in-depth understanding of the material behaviour and development of long-life SCLC.

A review of the concrete literature indicates that in contrast to workability, physical and mechanical properties of SCLC, no study has been conducted so far to investigate the combined rheological-related properties and durability performance of SCLC. In this work, the rheological-related properties and segregation resistance, strength development, pore structure and accelerated corrosion resistance of SCLC is experimentally studied and compared with those of conventional self-compacting concrete. In addition, the technique of X-ray computed tomography (CT) coupled with digital image software was used to visualise the micro-structures of the mixes.

2. Materials and methodology

2.1. Properties of materials used in concrete production

Ordinary Portland cement CEM I 52.5N conforming to BS EN standards was used to produce all concrete mixes. Fly ash was incorporated in the mix to supplement the cementing property and to enhance the workability of concrete. Local river sand with a specific gravity of 2.66 g/cm^3 constituted the fine aggregates in all mixes. Natural gravel sourced from a local quarry with a nominal maximum size of 14 mm and a specific gravity of 2.56 g/cm^3 was used to produce a control (reference) mix. The lightweight aggregate, kindly provided by Lytag Ltd., used was a sintered fly ash with a nominal maximum size of 14 mm. A graphical presentation of the gradings is displayed in Fig. 1. A polycarboxylate based superplasticizer with a specific gravity of 1.08 was also employed to achieve the desired workability in all concrete mixtures. The dosage of the superplasticizer was 1% by mass of powder.

2.2. Production of concrete mixtures

In all mixes, the volume fractions of cement, coarse aggregates, sand, superplasticizer and free water were the same. Thus, the same water–powder ratio of 0.31 was used in all batches. The only difference was the type of coarse aggregate used in the mixtures. The mix proportions are given in Table 1. Before casting concrete, lightweight aggregates were first immersed in water for 24 h until all particles were fully saturated.

A mechanical pan mixer was used for the mixing of the concrete. The fine and coarse aggregates were first introduced and mixed 1/3 of the water, which was gradually added. The fly ash and cement were incorporated in the mix with a substantial portion of the remaining water and mixed for 2 min. Finally, the superplasticizer with the remaining was added in the mixture and mixing continued for 3 min. From each mixture, cube and lollipop specimens were also cast without any compaction and vibration. 24 h after casting, they were de-moulded and cured at 20 ± 2 °C in a water tank until the day of testing.

2.3. Tests and analysis performed

2.3.1. X-ray diffraction analysis

Finely ground aggregate particles were placed and levelled in the sample holder and then positioned in the chamber of the Bruker –AXS D8 Advance XRD equipment which has a Cu-anode X-ray tube, a Göbel mirror, a diffracted beam collimator with a 0.12° Soller slit, and a Sol-X energy-discriminating X-ray detector set to Cu Kα radiation. The scanning was conducted between 5° and 70° at a speed of 2° per minute. The duration of the scan was about 60 min.

2.3.2. Accelerated corrosion resistance

Lollipop samples, 65 mm in diameter and 120 mm high, were also cast with 6 mm diameter mild steel rods in the centre. The 150 mm long steel rods were polished with SiC papers, cleaned with acetone and water respectively, and insulated with electrical tape to expose 30 mm of exposed steel at the bottom. A cover of approximately 32 mm was provided at the base of the concrete. The concrete lollipops were de-moulded after 24 h and were moist-cured for 27 days. At age 28 days, the specimens were placed in a cell with 10% NaCl solution.

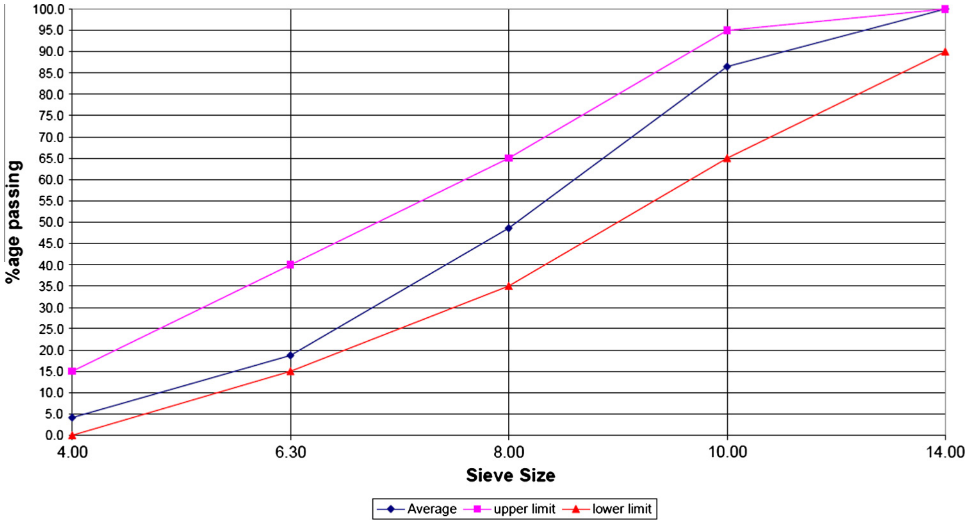

Fig. 1. A graphical presentation of the grading of the lightweight fly ash aggregate.