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Portland-composite and composite cement concretes made with coarse recycled and recycled glass sand aggregates: Engineering and durability properties

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HIGHLIGHTS

- CEM II/B-M cement recycled aggregate concrete mixes indicated either similar or slightly better loss of workability over time compared to corresponding CEM I cement RAC mix.
- Recycled aggregates concrete mixes showed dramatically lower compressive cylinder strength results compared to conventional natural aggregate concrete mixes.
- Drying shrinkage results showed that the contribution of pozzolanic reactions for Portland-slag and composites cement concretes takes place after 14 days.
- CEM II/B-M cement mixes indicated lower ISAT-10 values as the design strength class increased.
- Carbonation penetration results showed improvement as the design strength increased for the same cement type concrete mixes.

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ABSTRACT

Sustainable development approach demands the use of environmentally friendly materials. One possible way to encourage sustainable approach is via use of Portland cement (PC) replacement through use of permitted cement constituents in conformity with BS EN 197-1, to lower carbon footprint, and use of recycled aggregates as permitted within BS 8500, to encourage sustainability. Thus, this research study aimed to produce low carbon and sustainable concrete. For this aim, engineering and durability properties of equal 28-day design strength (40 and 50 N/mm^2) concretes made with Portland-composite and composite cements, CEM II/B-M and CEM V/A respectively, and partially substituted coarse recycled (RA) and washed recycled glass sand (RGS), 25% and 15% respectively, aggregates was investigated. The loss of workability was found to be larger for particularly CEM V/A and recycled aggregate concrete (RAC) mixes. Studies of hardened concrete properties, comprising bulk engineering properties (compressive cube and cylinder strength, flexural strength, drying shrinkage) and durability (initial surface absorption) showed enhanced performance for CEM II/B-M and CEM V/A mixes of equivalent strength natural aggregate concrete mixes (NAC), except resistance to carbonation. However, the use of CEM II/B-M and CEM V cements in RAC mixes slightly reduced the engineering and durability properties compared to corresponding NAC mixes.

1. Introduction

Reducing the carbon footprint of activities and a more prudent use of natural resources required for concrete production is a significant concern on the grounds of sustainable development. The United Kingdom (UK) construction industry is one of pioneer countries to implement sustainability and thus aiming to encourage prudent use of natural resources, avoid wastage and undue over-designing, reduce use of materials and recycle materials. In this respect, the UK has both international, The Kyoto Protocol, and national, Climate Change Act, targets to reduce the greenhouse gas emissions [1].

Current concrete practices may no longer be considered as sustainable due to PC, the most commonly used cement globally, is a high energy intensive material and its manufacturing requires

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consumption of raw materials such as clay, gypsum and limestone. In this regard, more environmentally friendly cement main constituents (CMCs) is permitted to be used in concrete production through the European Standard for common cements, BS EN 197-1 [2] to assist industry to achieve its commitments. Nevertheless, the main emphasis on available studies focussed on reducing the embodied CO_2 (ECO_2) emissions of concrete via substituting Portland cement (PC) with other permitted cement types in conformity with BS EN 197-1. Reducing the use of raw materials in the construction industry is another principle of producing sustainable concrete as the natural resources are running low in the world. Thus, Aggregate Levy has come into action by the UK government in order to prevent the use of natural resources and encourage the use of recycled or secondary materials. Primary aggregates, sand and gravel, are the most used materials in construction industry and use of these raw materials cause irreversible effects on the environment such as agricultural losses and rainforest destructions [3]. In the UK, the consumption of primary aggregates is assumed to be around 210 million tonnes whereas 43%, 90 million tonnes, of these are used in the concrete industry [4]. The use of coarse recycled aggregates (RA) in concrete is of significant interest due to its contribution to sustainable development by reducing demand on mineral extraction and minimizing landfill. RA is used in lower grade applications in conformity with BS EN 12620 [5] but it can also be used in higher grade applications when it meets and specifications of BS 8500 [6,7]. The use of recycled and secondary aggregates in the UK construction sector has increased over 70 million tones that account for 28%, the highest rate amongst European countries, three times the European average. However, the incorporation of recycled and secondary aggregates used in concrete accounts for 5.3% [8]. Use of recycled aggregates, where mostly consists of crushed concrete, are also encouraged in codes whereas BS 8500 allows RA to be used in designated concretes up to 20% except where the specification permits higher proportions to be used. However, there is no generic requirement on the use of recycled fine aggregates. The use of crushed recycled glass sand as a fine aggregate replacement in concrete reduces the overall greenhouse gas emissions and the use of natural aggregates, therefore, improves the sustainability credentials [9]. There is 1.85 million tonnes of glass cullet obtained from waste glass are being collected annually [10]. Having this said, the municipal recycling rate is 34% for container glass in the UK [11].

Jianyong [12] stated that concrete with 30% ground granulated blast-furnace slag (GGBS) replacement level and the same superplasticizer (SP) content increased slump value slightly than Portland cement (PC) concrete. Sabet [13] reported that "ball-bearing effect" of fly ash (FA) concrete with FA contents of 10% and 20% increased concrete slump and therefore reduced the amount of SP required to reach target slump. Another study by Limbachiya [14] revealed that FA concretes with higher binder content reduced the workability. Gesoglu [15] stated that the relationship between FA and workability loss could be attributed to the presence of FA when used in binary and ternary cements increased viscous characteristics of concretes. Erdem [16] also investigated that silica fume (SF) concretes may require more water as the SF increases due to SF has higher surface area, which this could be compensated by SP utilization. Tu and Chen [17] investigated that RA with higher absorption capacity comparing to natural aggregates have a slight influence on the concrete workability. Limbachiya [18] and Taha [19] stated that use of recycled glass sand (RGS) reduced the workability of the concrete due to lack of fine proportion. Taha [19] also reported homogeneity of the concrete was reduced in the presence of RGS which could be attributed to sharp edges of RGS increased the friction forces in the concrete matrix and thus reduced the consistency.

The use of CMCs has shown to reduce early strength of concrete but to improve long term mechanical performances [19–23]. However, the effect of CMCs on concrete durability is still ambiguous. Moreover, previous researches [24–28] have reported that the use of RA up to 30% showed slight reduction in mechanical and durability properties of concrete. Researches carried out on RGS concrete mixes have showed that the use of RGS up to 15% indicated comparable mechanical performances [29].

Previous studies [15,22,30] reported FA and GGBS additive ternary blend cement concretes indicated lower shrinkage compared to PC concrete and other ternary blend concretes. Kou [31] stated that increase in the drying shrinkage was proportional to the RA content used. According to Limbachiya [18], the use of RGS up to 20% was observed not to effect drying shrinkage.

Existing literature [26,28,32,33] on the use of CMC reduced carbonation resistance of concrete. Gönen and Yazıcıoğlu [24] investigated ternary blend (PC + FA + SF) concrete had lower carbonation depth which could be attributed to SF addition reduced concrete porosity. Jones and Dhir [34] investigated concretes made with ternary blend cements (PC-FA-GGBS) and found that ternary blend mixes had significantly higher carbonation depths compared to PC concrete. There is contradicting results on the behaviour of RA on the concrete carbonation resistance. Previous study by Kou [31] indicated that carbonation resistance decreased with the increased RA content. In contrast to that, Soares [35] stated RA did not have significant influence on the carbonation resistance and reported slightly higher results compared to reference mix. Castro and de Brito [36] investigated concretes with RGS contents of 5%, 10% and 20% by volume had improved carbonation resistance at long terms (56 and 91 days) due to refinement of the pore structure of concrete with the introduction of RGS.

Previous studies [20,25,34,13] revealed that use of CMC reduces the porosity of concrete due to pozzolanic reactions provided by the CMC. Thomas and Setien [37] stated increase in ISAT as RA content increases. Limbachiya [18] investigated an increase in the ISAT when RGS content is beyond 15% which was believed to due to increase in the porous matrix.

Existing standard, BS 8500, limits the use of RA to be used in structural applications and there is no specification regarding to the use of recycled fine aggregates in concrete production for structural purposes. In addition, there is little information available on the engineering and durability properties of concretes made with CEM II/B-M and CEM V/A cements and recycled coarse and fine aggregates. Thus, this study investigates engineering and durability properties of these concretes associated with the practical applications for the aim of low carbon and sustainable concrete production.

2. Experimental and testing programme

2.1. Materials

2.1.1. Cements

The cement types used were CEM I, CEM II/B-M and CEM V/A conforming to BS EN 197-1. A CEM I, 52,5N PC used for reference mix. Other cement main constituents used were GGBS, FA and SF and blended with PC to produce CEM II/B-M and CEM V/A cements for this study. GGBS was obtained from iron-making production in the UK conforming to BS EN 15167-1 [38]. FA and SF used were conforming to BS EN 450-1 [39] and BS 13263-1 [40] respectively. FA was obtained from Drax coal-fired power station in the UK. SF incorporated was in slurry form including 50% water and 50% silica powder. Physical properties and chemical composition of cement constituents used are given in Table 1.