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Case study

Mix design of light-weight self-compacting concrete

Behnam Vakhshouri*, Shami Nejadi

Centre for Built Infrastructure Research (CBIR), University of Technology Sydney (UTS), P.O. Box 123, Sydney, Australia

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A B S T R A C T

In recent decades, the utilization of mineral and chemical admixtures in concrete technology has led to changes in the formulation and mix design which has, in turn, made the concrete stronger and more durable. Light weight concrete (LWC) is an excellent solution in terms of decreasing the dead load of the structure, while self-compacting concrete (SCC) eases the pouring and removes construction problems. Combining the advantages of LWC and SCC is a new field of research. Considering its light weight of structure and ease of placement, Light-weight self-compacting concrete (LWSCC) may be the answer to the increasing construction requirements of slender and more heavily reinforced structural elements. Twenty one laboratory experimental investigations on the mix proportion, density and mechanical properties of LWSCC have been published in the last 12 years and these are analyzed in this study. The collected information is used to investigate the mix proportions including the chemical and mineral admixtures, light weight and normal weight aggregates, fillers, cement and water. Analyzed results are presented in terms of statistical expressions. It is very helpful for future research to choose the proper components with different ratios and curing conditions to attain the desired concrete grade according to the planned application.

1. Introduction

Generally the three major characteristics of concrete are workability, strength, and durability. It is believed that strength and durability are related to the hardened concrete and workability is related to the fresh concrete, however hardened properties may be directly attributed to the mix design and fresh properties. In other words, mix design and the fresh properties of concrete are the most critical points to control in relation to the mechanical characteristics of hardened concrete [6]. The early evaluation of hardened concrete properties is very important. The problem is that following the hardening process, the quality and mechanical properties do not improve. The structural behavior of concrete relies on mixing proportions and material properties of the composite system and these factors do not change after hardening.

Achievements in modern concrete technology have led to the introduction of light-weight concrete (LWC) and self-compacting concrete (SCC) as structure mass reducing and workable materials. LWC which is well known in the construction industry as opposed to SCC is an excellent solution for decreasing the dead load of the structure, while SCC is a modern material which facilitates the pouring and removal of construction problems. In recent years, some efforts have been made to combine the advantages of these two types of concrete in one package called light-weight self-compacting concrete (LWSCC). There are a wide range of publications about LWC concerning different light weight aggregates and mix

* Corresponding author. Fax.: +61295417142.
E-mail addresses: behnam.vakhshouri@uts.edu.au, behvakhsh@gmail.com (B. Vakhshouri), shami.nejadi@uts.edu.au (S. Nejadi).

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proportions. However SCC is a completely new topic in the construction industry and it has therefore attracted increasing research interest especially during the last decade. Since LWSCC is combination of two materials and one part is not fully investigated, it needs much more market research.

Despite different codes of practice about LWC mix design and some rare publications about SCC in the literature, there is no reference and technical draft about LWSCC mix design and its application. However, owing to the expected advantages of LWSCC in terms of cost efficiency and reduced construction time, research to comprehend the complicated nature of this new material is increasingly growing in different parts of the world.

Generally, the compressive strength of LWSCC is a fundamental parameter to estimate its other mechanical properties. In spite of available studies on the advantages of LWSCC associated with its high performance in the fresh state, there are less available studies regarding the expected hardened properties for mechanical responses like compressive strength. LWSCC is highly sensitive to changes in mix component properties and their proportions, therefore it requires increased quality control. The typical characteristics of LWSCC mix proportions, which are necessary to ensure adequate fresh properties, can have significant effects on hardened properties like strength, dimensional stability and durability [16]. For instance, the compressive strength of the LWSCC is influenced by the aggregate type and the water to cement and water to total powder [1].

The relation between cement paste and aggregates is very important in the mix design of concrete. SCC has a higher paste amount than conventional concrete and LWC to facilitate the flowing of aggregates to fill any voids inside the formwork. Paste coating of aggregates to reduce the friction and direct touching between aggregates can improve the flowability of fresh concrete. Controlling the water to cement ratio, results in a denser and stronger concrete. In LWSCC, this problem is even more obvious due to insufficiencies in the initial energy of lightweight aggregates in relation to moving along with the light weight aggregates in the cement paste [12]. To keep the balance among the proportions of LWSCC is therefore important to achieve the required flowability in the fresh state and the planned density and high quality in the hardened state.

Packing density theory is a method of concrete mix design which has been successfully used in LWSCC [13] by determining the optimum mortar to aggregates packing voids ratio. The main steps to attain the LWSCC mix design in this method are: (a) minimizing the voids volumes related to the coarse aggregate, (b) minimizing the water to cement ratio, (c) maximizing the density of the cementitious materials and (d) optimizing the flowability and requirements of the fresh concrete.

2. Conflict of segregation problem and flowability requirements

Although the mix design of LWSCC contains both LWC and SCC proportions, its special mix design does not exactly follow the mix design for these types of concrete. However the technological considerations and mixing problems in LWC and SCC still govern the LWSCC mix design. Fresh concrete is combined of fine and coarse aggregates suspended in a matrix of binder paste. Viscosity of the mortar and the volumetric fraction of the aggregates control the flow behavior. All studies evaluate the flowability of fresh LWSCC mixes by slump flow tests, J ring tests and V funnel tests according to the Self-Compacting Concrete Committee of EFNARC [8]. Although the workability aspects of LWSCC could be improved by approved suggestions in SCC, the LWSCC shows specific features that have resulted from using the lightweight aggregate [12].

The common problem reported in almost all published studies in relation to combining LWC and SCC is to ensuring the flow-ability of the fresh state and the low density of hardened concrete without segregation. Aggregate shape has a beneficial influence on the flowability of fresh concrete; however, when mixing the light and normal aggregates in LWSCC, the heavier aggregates tend to considerably sink [2].

Expanded clay, expanded granulated slag, expanded perlite or vermiculite and expanded polymer materials are frequently used light weight aggregates in LWC. Due to closed cavities, water absorption is high and so it is difficult to estimate the required water volume. Rising the water to the surface during mixing, in association with the tendency of light weight aggregates to float up, increases the segregation risk [12,3].

Some investigations [18] in the LWSCC mix design recommend applying the mix design method of high performance concrete for LWC in the mix to avoid the segregation problem and to keep the strength of the concrete high, in spite of applying light-weight aggregates.

3. Research significance

It is vital to investigate whether or not all the assumed hypotheses used to design conventional concrete, SCC and LWC structures are also valid for LWSCC structures. Almost all the published case studies including detailed information about the selection of components, mix proportions and the resultant fresh and hardened properties have been presented in this study. Despite the limited number of publications, the collected data gives the impression of being adequate for valid and useful systematic assessment of the variety of mix parameters and properties in statistical expressions. Above all, this will develop the idea of what can be expected with LWSCC for prospective users and researchers. This also gives interested and involved people a context in which to assess their own practices and to inform other researchers about their products.

The main objectives of this study are: