An analysis of the potential for improving cement efficiency through functionally graded concrete elements with durability-driven concrete specification

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Abstract

Cement, the primary binding component of concrete, is responsible for 5-6% of global CO2 emissions. In functionally graded concrete elements, properties are optimised by varying the concrete mix composition over the volume, allowing for allocation of cement intensive mixes only where necessary for resistance of load or aggressive substances. In practice, this is achieved by layering of different concrete mixes within the same formwork, providing an opportunity for reduction in overall cement content compared to conventional methods where a single concrete mix is used for entire elements. This work discusses possible applications for functionally graded elements that are optimised for durability resistance. Potential cement savings for various scenarios are calculated by comparison of traditional homogeneous concrete elements with functionally graded layered ones. The results show that the potential for reducing overall cement demand of structures whilst maintaining equivalent performance is significant.

Keywords: durability, mix design, functionally graded concrete

1 Introduction

Functionally graded concrete (FGC) describes a concrete element in which the material or structural properties are varied throughout the cross section. These variations are achieved by spatially varying the composition of the concrete mix. FGC is a growing area of research [1–4], owing to it's potential for improvement of cement efficiency in concrete structures, thereby leading to a reduction in embodied emissions.

Concrete durability describes the ability of a particular concrete to resist damage from environmental exposure during its service life [5]. A durable concrete will effectively resist processes which lead to accelerated corrosion of steel (such as carbonation and chloride ingress [6]), as well as physical (abrasion, freeze-thaw weathering) and chemical (sulphate) attack. Current design practice set out in the Eurocode BS EN 206:2013+A1 [7] requires designers to classify concrete elements into exposure classes dependent on the severity and nature of their environment – see Table 1.

Table 1. Exposure classes for durability specification, adapted from [[7]Table 1]

Class designation	Definition
X0	No risk of corrosion or attack
XC1 – XC4	Corrosion induced by carbonation
XD1 – XD3	Corrosion induced by chlorides other than from seawater
XS1 – XS3	Corrosion induced by chlorides from seawater
XF1 – XF4	Freeze-thaw attack
XA1 – XA3	Chemical attack (in UK this becomes ACEC)
XAS	Chemical attack from seawater

Mix design choices affect the overall durability of the concrete produced. Common measures used to improve resistance against various deterioration mechanisms are summarised in Table 2. Generally, durability of a traditional concrete is improved by reduction in the water/cement (*w/c*) ratio since this reduces the porosity of the material [8]. The consequence of this, for a workable mix, is an increase in the required cement content of the concrete.