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Investigation of effects of Portland cement fineness and alkali content on concrete plastic shrinkage cracking

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HIGHLIGHTS

- Using coarser cement gives higher cracking widths but reduced intensity of cracking.
- Increasing alkali content accelerates hydration and decreases water evaporation.
- Plastic shrinkage cracking is closely related to the kinetics of plastic shrinkage.
- Evaporation rate alone is not reliable and sufficient to assess risks of cracking.
- Low surface area and low alkali content cement is preferred for modern concrete.

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ABSTRACT

From a material viewpoint, modern concrete's frequent propensity to plastic shrinkage cracking can be attributable to a combination of low water-binder ratio use and ever-changing properties of binding materials. To obtain a better understanding of this phenomenon, this paper explores the effects of cement fineness and alkali content on the plastic shrinkage cracking of concrete manufactured with two water-binder ratios. Results indicate that within the range 275–385 m^2/kg, cement specific surface area is approximately directly and inversely proportional to hydration rate and evaporation rate respectively; a trend generally leading to higher plastic shrinkage and resulting areas of plastic cracking. Similar effects were observed for alkali contents which resulted in increased levels of plastic shrinkage. Furthermore, while decreasing crack tendency was noted as alkali content increased from 0.4 to 0.8% by mass of cement, further increases in alkali content caused significant decreases of compressive strength and slump; thereby lowering overall concrete performance. It is also found that plastic shrinkage cracking is closely related to the kinetics of plastic shrinkage. In summary, the experimental programme confirmed that cement with relatively low surface area (less than 340 m^2/kg) and low alkali content (less than 0.8%) is preferred for modern concretes with minimal plastic cracking problems.

1. Introduction

Plastic shrinkage refers to shrinkage of concrete occurring in the first 24 h after batching, caused by external drying and cement hydration effects [1,2]. These cracks do not only affect aesthetics of structures, but also permit transport of moisture and other aggressive species. As a result, concrete strength and durability performance can be compromised [3,4]. Reflecting its seriousness, the topic of plastic shrinkage and cracking has been the focus of concrete researchers and engineers for decades [5–7].

Despite best efforts to avoid the problem [2,6,7], plastic shrinkage cracking is still very common in regions where the weather is hot and dry. This is particularly true for modern concretes which appear more sensitive to cracking immediately after setting [8]. From a material point of view, the main factors attributing to this trend include changes in binder material properties, high binder contents, low water/cement ratio (W/C) and admixture use and

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variability [9,10]. As such, high cracking frequencies cannot be considered as completely unexpected. While considerable literature exists covering different parameter effects on plastic shrinkage and plastic cracking [2,9,11,12], the influence of cement properties is still relatively unexplored. Clearly this knowledge would provide construction professionals with a relatively straightforward material specification approach to reducing risks associated with plastic cracking.

This guidance would, for example, be particularly welcomed by construction professionals in China. After 20 years of development focussed along its eastern seaboard, considerable infrastructure construction is now underway in the south west of China.

A general concern for the construction industry in this area is plastic cracking due to the demanding environment conditions in this region where temperatures at concrete surfaces in the summer can easily reach 60 °C with wind speeds varying from 5 to 10 m/s. Furthermore, while properties of local cements have undergone several changes in recent years, few published reports outlining these changes, not to mention their effects on plastic shrinkage cracking, are available.

Conscious of these problems, a western traffic science and technology project was funded in 2009 to survey properties of cement throughout the southwest part of China and investigate their effects on plastic cracking [13]. Chemical and physical properties of cements from 233 manufacturers were examined and the primary results are given Fig. 1. It can be seen from Fig. 1 that around 86% of cements have a specific area varying from 320 to 360 m^2/kg, with 9% having an even higher specific area (>360 m^2/kg). The other trend noted is high cement alkali content, with 95% samples having values higher than 0.6% by mass. These trends in cement production are similar to those experienced in Western counties, where finer materials were introduced to deliver perceived performance benefits such as increased strengths, reduced cement contents for a given specific strength, earlier removal of formwork, and faster construction times [14–16]. Unfortunately, such benefits are also associated with potential disadvantages such as an increased risk of plastic shrinkage cracking.

This paper addresses the effect of Portland cement quality, namely in terms of fineness of cement particles and alkali content, on plastic shrinkage cracking. A comprehensive experimental programme is reported with results for hydration rate, evaporation, plastic shrinkage, crack width and cracking area presented. These results are intended to provide engineers and contractors with an insight into the fundamental behaviour of plastic cracking and assistance in selecting proper approaches to its avoidance.

2. Experimental programme

2.1. Experimental variables investigated

Based on data obtained from the aforementioned survey of cement [13] and relevant literature [17–19], the three main parameters considered in this study were cement fineness, cement alkali content and water-cement ratio (W/C). As summarised in Table 1, ranges considered for these properties were 275–385 m^2/kg, 0.4–1.2% by mass and 0.35–0.40 respectively.

To prepare cements with different fineness and alkali contents, pure clinker manufactured from Lafarge, as characterised chemically in Table 2, was used. The clinker was ground for different periods in a ball mill to yield the required fineness levels of 275, 337 and 385 m^2/kg. In each case, gypsum was added at a rate of 5% by mass.

Alkali contents were adjusted by adding NaOH (chemical pure) into water during the concrete mixing stage to ensure equivalent cement alkali contents of 0.4, 0.8 and 1.2% by mass.

The effect of W/C (0.35 and 0.4) on shrinkage-induced cracking was also investigated, mainly because low W/C is a key feature of modern concretes generally leading to increased autogenous shrinkage and early age cracking sensitivity [12,20].

As plastic shrinkage cracking relies heavily on numerous parameters, including: water evaporation rate; settlement and capillary pressure; hydration kinetics; concrete materials and mix proportions; and environmental conditions (e.g. temperature, relative humidity and wind speed) [5,11,18], assessment of its risk

Table 1
Summary of experimental variables.

Factors and levels			
Factor	Cement fineness	Alkali content	W/C
Level	275, 337, 385 m^2/kg	0.4, 0.8, 1.2% by mass of cement	0.35, 0.40
Property determined			
General property	Slump, Compressive strength at the age of 3, 7 and 28 days		
Influencing property	Cement hydration, Water evaporation rate, Plastic shrinkage		
Response property	Maximum cracking width, Cracking area		

Note: the value of 275, 337, 385 m^2/kg refers to specific area of cement particles; the value of 0.4, 0.8, 1.2% refers to alkali content, calculated based on Na_2O mass percent.

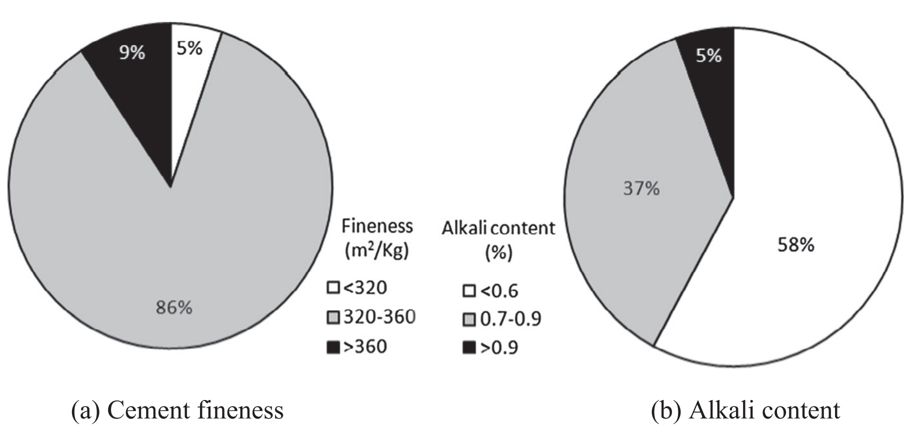

Fig. 1. Summary of results of fineness and alkali content for cements commonly used across southwest China.