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Limestone addition effects on concrete porosity

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ABSTRACT

The effect on porosity (including absorption and sorpitivity) of cement paste and mortar/concrete, of limestone addition to Portland cement is assessed. Based on globally sourced literature published in English since 1993, consisting of 171 publications from 35 countries. The data analysed were from wide ranging tests. The effect on pore structure was also examined in terms of type of Portland cement and limestone, cement fineness and method of producing it, curing, maturity and water-cement ratio, as well as the cement composites with fly ash, slag (GGBS), silica fume and metakaolin and related to strength. Overall, it is suggested that though the use of limestone up to 25% with Portland cement should not impair the pore structure, limit on limestone content for its effect on strength is likely to be about 15%. This should be considered where higher proportion of limestone content is allowed in the Standards.

1. Introduction

Although limestone has been one of the base materials used in the manufacturing of Portland cement (PC) ever since it was first developed in the 1824, its use as an addition to cement is relatively new and is closely associated with the global sustainability drive. In fact, it is claimed that the use of limestone can lessen carbon footprint of concrete by about 15% [147], as well reducing the demand for primary raw materials for cement by around 10% [130]. Furthermore, limestone is also a cheap material and easier to handle for cement manufacturers; it results in lowering grinding effort [15] and it is available at the cement plant.

The use of limestone in the form of blended cement in combination with PC, now commonly known as Portland limestone cement (PLC) was first attempted in 1965 in Germany. French Standards adopted its use in 1979 and in 1983 the Canadian Standards permitted 5% limestone to be combined with cement [70]. In 1992 British Standards allowed the use of limestone up to 20% and now its use is recognised in the national Standards worldwide (Table 1), with the maximum limit for limestone content in some cases increased to 35% (BS EN 197-1:2011 [22], EN 197-1:2011 [52], SANS 50197-1:2013 [142], SS EN 197-1:2014 [137] and NMX-C-414-2010 [105]).

As to be expected, the usage of PLC has been recently increased rapidly, particularly in Europe [79] and a great deal of research has been undertaken and published on its performance relating to the fresh and hardened states of concrete, as well as the various aspects of durability. However, the published literature was remained fragmented and this does not help in assessing the sustainable use of the material, in a realistic and reliable manner.

A long term view of promoting sustainable construction, calls in question how the use of PLC may affect the permeation and durability of concrete as well in fundamental terms the development of its pore structure which is commonly referred to in practice as porosity and commonly measured as absorption and sorpitivity. Whilst the importance of porosity on the durability of concrete is widely recognised, the relationship between the two is not so clear particularly with different cement type.

Given the above, the study has been initiated to examine the global literature, published in English by analysing and evaluating the published data to assess the effect of limestone addition on the porosity of concrete.

2. Aim and objectives

The main aim of this study is to assess the effect of limestone use as cement component on the porosity, (including water absorption

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Table 1
Limestone contents permitted in Portland limestone cement in some national and international standards world-wide.

Country	Limestone content, %	Standard/source
(a) Standards use 35% maximum limestone addition level		
UK and Europe	CEM II/A: 6 to 20	BS EN 197-1:2011 [22];
	CEM II/B: 21 to 35	EN 197-1:2011 [52]
South Africa	CEM II/A: 6 to 20	SANS 50197-1:2013 [142]
	CEM II/B: 21 to 35	(based on EN 197-1:2011)
Singapore	CEM II/A: 6 to 20	SS EN 197-1:2014 [137]
	CEM II/B: 21 to 35	
Mexico	6 to 35	NMX-C-414-2010 [105]
(b) Standards adopt maximum limestone addition level below 35%		
USA	>5 to 15	ASTM C 595-M-2015 [8]
	>5 to 15	AASHTO M240–2015 [7]
Canada	>5 to 15	CSA A3001-2013 [27]
Australia	8 to 20	AS 3972-2010 [143]
New Zealand	up to 15	NZS 3125:1991 (Amended in 1996) [144]
China	up to 15	[69]
Iran	6 to 20	[122]
The former USSR	up to 10	[146]
Argentina	≤20	[146]
Brazil	6 to 10	[146]
Costa Rica	≤10	[146]
Peru	≤15	[146]

and sorpitivity) of cementitious mixtures (such as cement paste, mortar and concrete) and establish how this may be used in practice. In achieving this aim, the following objectives have been adopted:

(i) To develop and overview the published literature on the effect of PLC on porosity, and for practical reasons, including absorption and sorpitivity, of cementitious mixtures in the form of cement paste, mortar and concrete.
(ii) To analyse and evaluate the published data on porosity (including absorption and sorpitivity) of concrete in a manner that may suggest an optimum level for limestone addition use in concrete.
(iii) To propose the ways for the use of PLC more efficiently in practice.

3. The effect of limestone addition

Overview of the observed effect on the pore structure, in terms of porosity, water absorption and sorpitivity, of cementitious mixtures (paste, mortar and concrete) of using limestone addition, similar to the specifications adopted in the Standards such as BS EN 197-1:2011 [22], is presented in Table 2. This is based on the preliminary study of the data presented in the literature, consisting of 97 studies published over a period of 23 years from 1993 to 2015.

Given the large number of parameters involved across the literature, the only viable option available was to initially examine all the data with limestone use relative to the corresponding PC mixtures and assign them to one of the five categories w.r.t. porosity and related properties, expressed as being:

(i) Higher than PC.
(ii) Lower than PC.
(iii) No change.
(iv) Variable, where the relative figures change with limestone content
(v) Unclear, where reference PC data has not been provided.

Additionally, the causes for the observed data as stated by the researchers in each case have also been summarised in Table 2. The physical and chemical effects are mainly identified as the filler, heterogeneous nucleation and dilution effects [77] as follows:

- The filler effect of limestone refines and improves the porosity of the mix and in general terms results in lowering the water demand for a given workability [77].
- Heterogeneous nucleation takes place since limestone particles work as nucleation sites, raising the early hydration of cement and, consequently, creating an additional mixed up crystallization of calcium silicate hydrate [135].
- The dilution effect acts in reverse to the filler effect and heterogeneous nucleation. The dilution effect is an outcome of the reduced cement content and, as a result, an increase in the effective w/c of the test mix [77].

The above effects are in essence considered to rely on the amount and fineness of limestone addition used in a particular mix [135].

The obvious overall impression to emerge from the preliminary initial examination of the literature as presented in Table 2 is one of split opinion regarding the effect on porosity and related properties of cementitious mixtures (cement paste, mortar and concrete) with limestone use as cement component.

Further examination of the literature revealed that the variability observed in the initial appraisal of literature appears to be caused by the number of parameters involved in the reported studies and adding to the assessed variability of the effect of limestone inclusion, such as the:

(a) Proportion of limestone used in relation to Portland cement content ranging from 2 to 50% and about one-third of the studies used only one limestone proportion level.
(b) The different test methods used and the procedures adopted, the age at test varying from 1 to 365 days and with it the limestone effect not remaining constant throughout.
(c) Water/cement ratio varying from 0.35 to 0.79 and with a given mix the PLC effect varying.
(d) Fineness of cement mixture and mineralogical composition of Portland cement.

Notwithstanding the above, and the uncertainties thus arising for not being able to establish a clear consensus on the effect of limestone use on the porosity and related properties of