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Durability performance of sustainable self compacting concretes in precast products due to heat curing

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HIGHLIGHTS

- Modifications caused by heat curing in the properties of 2 types of SCC are evaluated.
- Two work scales are considered: laboratory and industrial plant.
- The durability loss due to heat curing must be compensated in the mix design process.
- Replacing 20% of cement with limestone filler promotes a more refined porosity.
- A more sustainable heat cured concrete with similar durable behavior is obtained.

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ABSTRACT

Heat curing, which is used to ensure the production rate, influences the microstructural and durability properties of the concrete. When a given performance is required, the influence of the heat curing in the concrete properties must be considered in the concrete design process. This paper evaluates the influence of heat curing on several parameters of two self-compacting concretes (SCC) produced in laboratory and at industrial scale, one of them designed based on sustainable issues (replacing 20% of cement with limestone filler). The obtained results show that the heat curing process modifies the properties of both concretes in a similar way thus more sustainable heat cured SCC can be fabricated.

0. Research significance

This paper shows a study carried out both in laboratory scale and at a real industrial scale. The consideration of both work scales allows a more accurate interpretation of the obtained results and it is a very good example of the mutual benefits that arise from the association between the industry and the research activities. The analysis of the final product, i.e., submitted to the actual curing regime, is not commonly found and its characterisation on a performance basis may lead to improvements in the design process and to further innovations in the industrial process. In the present paper the effect of the heat curing on many durability parameters, even those related to concrete reinforcement corrosion, have been evaluated on two types of concretes. Limestone filler is included in one of them, partially replacing the cement content, which allows for the fabrication of a more sustainable concrete without compromising the required service life of the final product. Therefore, the influence of replacing 20% of cement by limestone filler in the durability parameters previously mentioned has been evaluated.

1. Introduction

The use of self-compacting concretes (SCC) is mainly widespread in the precast industry. Precast concrete elements are used in construction to improve the quality of concrete production and to reduce the construction time [1]. Besides, heat curing processes are often used to ensure the production rate of precast concrete structures, as this process increases the early strength of the material. However, this increase in curing temperature influences the final mechanical properties negatively [2–4]. This handicap must be taken into account in the design process in order to fulfil the final requirements and the high quality demanded.

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From 7 days on, the rapid initial hydration affects the strength because the physical structure of the hydration products formed is less robust thus retarding hydration at later ages. This is caused by the insufficient time and the scarce space available for the hydration products to separate from the cement grains and precipitate evenly into the interstitial space. The resulting high concentration of unevenly distributed products prompts higher porosity, adversely affecting later age strength [5]. However, some authors have stated that the heat curing does not increase the total porosity of the concretes but promotes a different pore size distribution, increasing the amount of bigger pores [6,7] or the fraction of mesopores and macropores [8]. In fact, the changes in the pore size distribution depend on the steam curing duration [9]. Moreover, regarding the modifications in the hydration products, curing at elevated temperatures leads to reduced surface areas of the hydrates formed, limits an adequate distribution of reaction products and can modify both the composition and the morphology of the C–S–H phases [6,10].

Despite heat curing is commonly used in pre-cast industry, researches on heat cured products mainly focus on their strength development but investigations on the influence of this accelerated curing process on the durability properties of the precast products are limited and the published results are contradictories. In this sense, some durability indicators have been analysed in literature. Considering water sorptivity results, some researches who used different maximum temperatures of curing, determined that for Ordinary Portland Cement (OPC) concrete, heat curing produced a vastly inferior product [10–12] because it may considerably influence the microstructure. Water permeability and surface resistivity may also be affected [13]. It has been also observed that long-term properties are negatively influenced by elevated curing temperatures [2,3].

However, there is a lack of knowledge in the possible influence of the heat curing on some direct durability parameters that are very important considering the reinforced concretes service life, as the resistance against both carbonation and chloride penetration. Thus, it is necessary to improve the knowledge of the influence of the heat curing on the durability properties of the concretes to take them into account in the design process when a given service life is required. Nevertheless, in order to compensate the expected durability-related properties loss, the cement content must be increased. This solution increases the cost of the final product and decreases its sustainability.

Therefore, this paper deals with two main issues: (1) the evaluation of the influence of the heat curing process on physico-mechanical and microstructural parameters of a precast heat cured SCC; (2) the improvement of the sustainability of the concrete while maintaining its potential durability and other functional requirements. In this last concrete the cement content was significantly reduced by adding limestone filler that significantly increases its workability. The influence of the heat curing in the more sustainable concrete was also evaluated.

Accordingly, both concrete types were evaluated in standard curing conditions (100% Relative Humidity, RH, and 21 °C) and after heat curing. Furthermore, as this is a collaborating study between the industry and some research institutes, the study was carried out both in laboratory scale and at a real industrial scale. This has allowed for a more accurate interpretation of the obtained results.

2. Experimental

2.1. Materials and mix proportions

The Portland cement used in this study complied with UNE-EN 197-1 and it was labelled as CEM I 52,5 R. The chemical composition of this cement is shown in Table 1. Siliceous sand (0–4 mm), limestone sand (0–6 mm) and siliceous coarse aggregates (6–12 mm) were used. Limestone filler with a mean size of 9 μm was used in the more sustainable concrete. Two policarboxilate based superplasticizers were also used. The absolute volume method was followed to calculate the mixtures proportions, whose water/binder ratios were 0.4 in both concrete types. In the present paper H refers to the SCC with higher cement content and F refers to the SCC with limestone filler. The cement content of the F concrete was 20% lower than the one of the H concrete.

Table 1
Chemical composition (wt.%) of the OPC used.

LI	IR	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
1.95	2.87	19.7	4.68	3.15	61.0	2.32	3.66	0.45	0.98

LI: loss of ignition; IR: insoluble residue.

2.2. Casting, curing and testing

Four different sets of samples, made of identical concrete composition, have been evaluated:

- Concrete directly cast at the plant and stored in standard curing conditions (28 days at 100%RH and 21 °C).
- Concrete made in the laboratory and stored in standard curing conditions (28 days at 100%RH and 21 °C).
- Concretes cores extracted from a precast element made at the precast plant, after the current heat curing process.
- Concrete made in the laboratory, submitted to a heat curing process that reproduced the one carried out in the plant.

Table 2 summarises the different sample types considered in this study. The specimens were cylindrical samples 7.5 by 15 cm (diameter; height) but the cores extracted from precast concrete containers were 4 by 8 cm sized. The precast concrete containers were made in two parts; the floor and walls were monolithic and so were cast as a unique piece, while the roof was cast as a separated part and positioned at the end, once all the required electrical equipment was installed inside the containers. To ease the filling process, the floor and wall were cast at the upside down position and shortly after casting, the steel moulds were heated with water vapour. Concrete remained in the formwork for a limited time and then, the forms were removed and the whole piece was rotated 180° up to the upright position. The concrete cores used in this study were extracted from the roofs of several concrete containers. The roofs were rectangular pieces 6080 by 2380 cm sized.

Several parameters were evaluated 28 days after the concrete fabrication. The parameters evaluated in the four sample types of each concrete type were:

(1) Mechanical properties: assessed by the compressive strength following the UNE-EN 12390-3 standard, except for the too short cores as they were tested for indirect tensile strength (UNE 83306/UNE-EN 12390-6). Three samples per concrete type and curing age were evaluated. In this case different curing ages were considered: 1, 2, 4, 7, 17 and 28 days.
(2) Total porosity and pore size distribution using a Mercury Intrusion Porosimeter (MIP, Micromeritics porosimeter Model 9320). A piece of concrete with approximately 1 cm^3 was used. Two pieces of representative portion of each concrete type were analysed.
(3) Capillary suction coefficient after submitting the samples to a specific preconditioning. Water absorption rate by means of capillary test (based on the standard UNE 83982) was measured. One face of the specimen was put in contact with a 5 mm water head, into a covered receptacle. Capillary suction coefficient was calculated from weight-increase-over-time data. Three samples per concrete type were analysed.
(4) Microstructure: samples were examined using backscattered electron imaging of polished surfaces. Samples were embedded into an epoxy resin, cut, polished and then coated with carbon. A JEOL JSM 5400 scanning electron microscope (SEM) equipped with a solid-state backscattered detector and a LINK-ISIS energy dispersive (EDX) was used.
(5) Resistance against carbonation: the concretes were exposed to natural atmosphere with a mean RH ≈50% (protected from rain) during 12 months. After this period the carbonation depth was measured and the carbonation velocity was calculated according to the equation:

$$X = k\sqrt{t}$$

where X if the carbonation depth measured (cm), k is the carbonation velocity (cm/year$^{0.5}$) and t is the exposure time (year). Three samples per concrete type were analysed.

(6) Resistance to chloride penetration, using the commonly called "Ponding Test", was also assessed. Saturated concrete samples were in contact with a NaCl 1 M solution for 12 months and, after this time, the chloride penetration profiles were determined. According to the profiles obtained, the