Construction and Building Materials xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

An analysis of the steam curing and autoclaving process parameters for reactive powder concretes

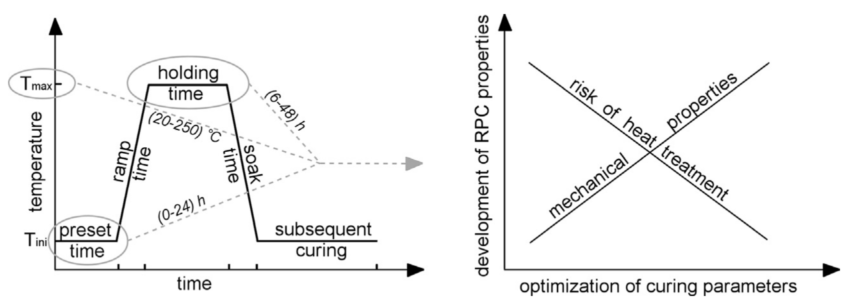
Tomasz Zdeb

Cracow University of Technology, Warszawska 24, 31-155 Cracow, Poland

HIGHLIGHTS

- The optimum RPC steaming and autoclaving parameters were determined.
- The efficiency of steel fibres depending on RPC curing conditions was investigated.
- The changes in microstructure of RPC cured at elevated temperature were described.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 February 2016
Received in revised form 13 October 2016
Accepted 6 November 2016
Available online xxxx

Keywords:
Reactive powder concrete
Steam curing
Autoclaving
Mechanical properties
Microstructure

ABSTRACT

The two different methods of thermal treatment were used when curing reactive powder concretes (RPC), namely low-pressure steam curing and autoclaving. The properties of obtained material were referred to those of materials cured in water at a temperature of 20 °C. The main aim of this study is to verify mechanical properties of RPC without fibres, at variable steaming and autoclaving parameters. The following factors were taken into account: preset time, target temperature and holding time. At the same time by using the techniques of SEM and MIP, changes in microstructure of composites cured at an increasing temperature and different time were observed. After establishing the most favourable heat treatment parameters, their effect on the efficiency of steel fibres of 6 mm long added at amount of 2% by volume was analysed. Compressive strength and three-point flexural strength were tested along with deformability evaluation. The factor having the strongest effect on mechanical properties of RPC under examination was the target temperature of steaming and autoclaving. RPC curing conditions had also a significant impact on post-critical strains in composites containing dispersed reinforcement.

1. Introduction

In recent years many work has been done to improve reactive powder concrete properties by application of sophisticated treatment during setting of this cementitious and high performance composite. The impact of selected heat treatment parameters on RPC properties was studied by [1–3] as well as the effect of compression [4] and vacuuming [5] of concrete mixture was evaluated. This comprehensive research is focused on both steaming and autoclaving processes of RPC, in order to establish their optimal parameters.

The steaming process (S) carried out at a temperature not exceeding 100 °C, thus at steam pressure below 1 bar, at first place is aimed at accelerating the binder hydration processes that in turn may lead to reaching high material strength in a relatively short time. However, improperly selected steaming parameters, and at first place preset time may lead to some adverse phenomena, for example DEF type corrosion [6]. Improperly controlled curing of a material at elevated temperature may reduce strength parameters due to another reason. The products of calcium silicate

E-mail address: tzdeb@pk.edu.pl

http://dx.doi.org/10.1016/j.conbuildmat.2016.11.026
0950-0618/© 2016 Elsevier Ltd. All rights reserved.

hydration, naturally formed, are characterised of strongly developed specific surface area that is reduced by increasing temperature. This in turn may cause their poorer adhesion to composite aggregate grains [7]. RPC steaming cycles used by various researchers are highly differentiated. Both preset time changing from few hours 0–6 [8,9] and reaches even few days 3–7 [2], as well as material holding time at the maximum temperature from 9 to 96 h [9,10] are varied. However, the low-pressure steaming temperature in the vast majority of publications is 90 °C.

The properly selected autoclaving cycle parameters (A), a hydrothermal treatment carried out at a temperature above 100 °C and pressure higher than 1 bar, like steaming cause a rapid increase in mechanical properties, and also reduction in porosity, shrinkage and an increase in resistance to chemical aggression. The autoclaving process eliminates, among other things, the occurrence of secondary ettringite. This results from the fact that a significant amount of Al^{3+} and SO_4^{2-} ions are built in the structure of hydrated calcium silicates during hydrothermal treatment [11–14]. Additional advantages resulting from autoclaving cementitious materials, including RPC, are related to changes in its structure consisting primarily in the appearance of crystalline forms of hydrated calcium silicates. The type of formed ordered C-S-H structures depends on many factors, among other things, on temperature, pressure, C/S ratios for substrates or guest ions that stabilize some phases. In autoclaved cementitious materials tobermorite and xonotlite of very well investigated and described structures [10–12] occur as the most common phases. The occurrence of both phases in autoclaved RPC materials was confirmed by a number of researchers [15–18]. However, it should be noted that there are some unfavourable CaO/SiO_2 proportions at which crystallization of hydrated calcium silicates leads to formation of such phases as α-C_2SH or truscotite causing the deterioration of mechanical properties of cementitious materials [11]. There is a very wide range of RPC autoclaving parameters used. Target temperature varies from 160 up to 400 °C, while treatment at 400 °C is performed outside the autoclave, causing an increase in pressure inside the material characterized of very tight structure. However, holding time reported in the literature varies between 8 and 24 h [8,12,19].

So far many studies pertaining mechanical properties of RPC cured in various hydrothermal conditions, i.e. in standard wet environment at 20 °C, during low-pressure steaming (S) or autoclaving (A) were carried out. It is difficult to compare material properties described in publications due to differentiated treatment parameters at elevated temperatures, and in addition these materials are of different composition in terms of binder content and fibre content and length. The completed research program presented below consists in its first part in choosing the most favourable parameters of low-pressure steaming and autoclaving for RPC without fibres. In the second part of this research a comparative study of compressive strength and material response during bending test for a material containing steel fibres, steam cured and autoclaved with optimized parameters and a material cured in water at 20 °C for 28 days was made.

2. Experimental study

2.1. Materials

To obtain reactive powder concrete the ordinary Portland cement (OPC) of 52.5 strength class according to EN 197-1 characterized of essential properties for RPC composites, i.e. low alkaline content, high silicate modulus exceeding 3.5 and relatively low specific surface area was used. In addition, quartz sand of 0/0.5 mm in grain size, quartz powder (0/0.2 mm), silica fume (SF), and polycarboxylate based superplasticizer were used. Brass coated steel fibres of 6 mm in length and 0.175 mm in diameter of 2200 MPa in tensile strength, density of 7.76 g/cm^3 and modulus of elasticity of 210 GPa were used. Steel fibres were incorporated to concrete mixture during second stage of the research, i.e. once all the curing parameters at elevated temperature were established.

Table 1
Chemical, physical and mechanical properties of RPC components.

	Cement	Silica fume	Quartz powder	Quartz sand
Chemical composition [%]				
SiO_2	22.98	94.06	99.0	98.5
Al_2O_3	4.41	0.74	0.3	0.8
Fe_2O_3	2.10	0.78	0.05	0.03
CaO	65.58	0.06	<0.1	–
MgO	1.06	0.49	<0.1	–
Na_2O_e	0.51	1.43	0.2	–
SO_3	3.32	0.63	–	–
Cl^-	0.009	–	–	–
Mineral composition [%]				
C_3S	59.1	–	–	–
C_2S	18.0	–	–	–
C_3A	8.1	–	–	–
C_4AF	6.4	–	–	–
Physical and mechanical properties				
Specific surface [m^2/g]	0.41	22.4	0.8	0.04
Density [g/cm^3]	3.10	2.23	2.65	2.65
Initial setting time [min]	130	–	–	–
Final setting time [min]	220	–	–	–
Compressive strength after 2 days [MPa]	35	–	–	–
Compressive strength after 28 days [MPa]	71	–	–	–

According to [20,21], in order to ensure the highest packing density for dry composite ingredients when choosing micro-aggregate proportions the optimum grain size distribution curve proposed by Funk and Dinger was applied [22]. As the result of analysis carried out quartz sand was mixed with quartz powder at the ratio of 30/70%. Detailed information on chemical, physical and mechanical properties of all grained components is shown in detail in Table 1, while corresponding grain-size distribution is presented in Fig. 1. The RPC composition is specified in Table 2.

2.2. Experimental procedures

Preparation of concrete mixture started from preliminary mixing of all dry concrete components for 1.5 min, and then 75% of assumed water amount was added and with an admixture introduced earlier mixing was continued for 1.5 min. The mixing

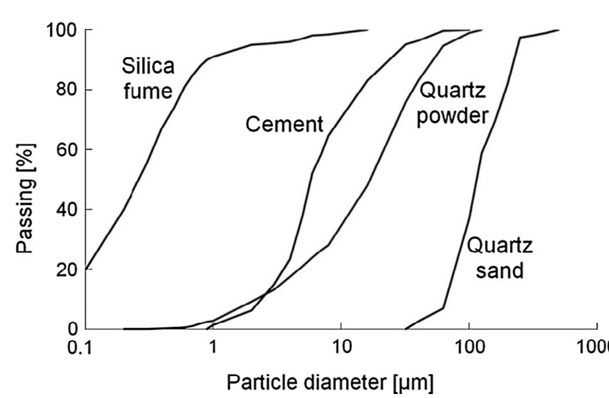


Fig. 1. Grain-size distribution for RPC components.

Please cite this article in press as: T. Zdeb, An analysis of the steam curing and autoclaving process parameters for reactive powder concretes, Constr. Build. Mater. (2016), http://dx.doi.org/10.1016/j.conbuildmat.2016.11.026