EFFECT OF CURING CONDITIONS AND STEEL OR GLASS FIBRES CONTENT ON MECHANICAL PROPERTIES OF REACTIVE POWDER CONCRETE

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Abstract

The paper deals with the compressive and flexural strength (tensile strength at bending) test results of the RPC composite developed at Cracow University of Technology. The following curing conditions were applied: natural conditions, steam curing and autoclaving. The influence of volume of steel or glass fibres on both compressive and flexural strength was examined. The best results were achieved when a 4 % vol. of steel fibres was used and the specimens were subjected to autoclaving. The compressive and flexural strengths obtained were 315 and 27 MPa respectively. The influence of glass fibres on compressive and flexural strength was insignificant.

Keywords: reactive powder concrete, ultra high performance cementitious composites, steel fibres, glass fibres, curing conditions, strength

1 Introduction

One of the modern composites with a cementitous matrix is an ultra-high strength material, classified as a low-temperature ceramics. Production of this material is possible due to progression of cementitious binders technology, efficiency of new generation superplasticizers and also wide knowledge regarding influencing of mineral additions on microstructure and properties of cementitiuos materials. Like well known High Performance Concretes (HPC), the Reactive Powder Concrete (RPC) is the result of long-lasting research, which result was reduction of typical shortcomings of cementitious Ordinary Concrete (OC).

Bache [1] and Birchall [2] pioneered the design of a new generation material. Composition and the technology of reactive powder concrete (RPC) were developed in France in the mid 90's [3]. Depending on the technological procedures in production of the RPC composites, its compressive strength can range from 200 to 800 MPa and its flexural strength from 20 to 40 MPa [3]. Currently one RPC product is manufactured by the French company Lafarge and named Ductal® [4].

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2 Materials and specimen preparation

2.1 Mix composition

The following components were used: portland cement CEM I 52,5R, silica fume, ground quartz 0/0,2 mm, quartz sand 0/0,5 mm and ordinary acrylic-based superplasticizer. Additionally straight and smooth steel fibres (Fig. 1a) and alkali-resistant glass fibres (Fig. 1b) were included.

RPC's examined matrix composition is presented in table 1. The proportion of components was fixed in a wide variety of literature [5-24] and self research [25, 26, 27].

Tab. 1 Composition of RPC matrix by weight ratio

Cement CEM I 52,5R	1.00
Silica fume	0.20
Ground quartz 0/0,20 mm	0.34
Quartz sand 0/0,50 mm	0.81
Superplasticizer	0.02
Water	0.24

The mixture above includes steel fibres in turn 0.5; 1; 2; 3 and 4 % vol. (equivalent 39, 78, 155, 233 and 310 kg/m^3) or glass fibres 0.25; 0.50; 0.75 and 1.00 % vol. (equivalent 7, 13, 20 and 27 kg/m^3). The maximum content of steel and glass fibres was 4% and 1% vol. respectively, defined by obtaining proper workability of the concrete mix without changing its composition.

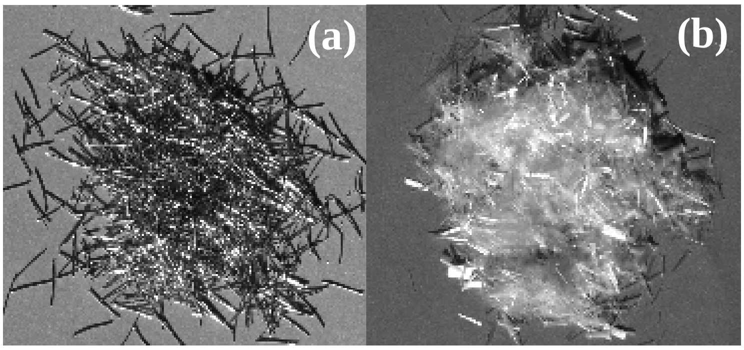

Fig. 1 Applied steel fibres (a) glass fibres (b)

Tab. 2 Properties of applied fibres

Feature	**Steel fibres**	**Glass fibres**
Length [mm]	6	3
Diameter [µm]	175	14
Tensile strength [MPa]	2200	1700
Elastic modulus [GPa]	210	72
Density [g/cm^3]	7.76	2.68

2.2 Specimen preparation and curing conditions

The mixtures with and without fibres were moulded and densified in a gravitational manner. Beams 40x40x160 mm were used as specimens. The preliminary setting of the concretes lasted for 6 or 24 hours at +20°C, where evaporation of water was prevented. After de-moulding, the specimens were cured in three different conditions:

- curing in water at +20°C, after 24 hours of preliminary setting,
- steam curing at +90°C, according to the cycle (Fig. 2),
- autoclaving at +250°C and in pressure 40 bar, according to the cycle (Fig. 2).

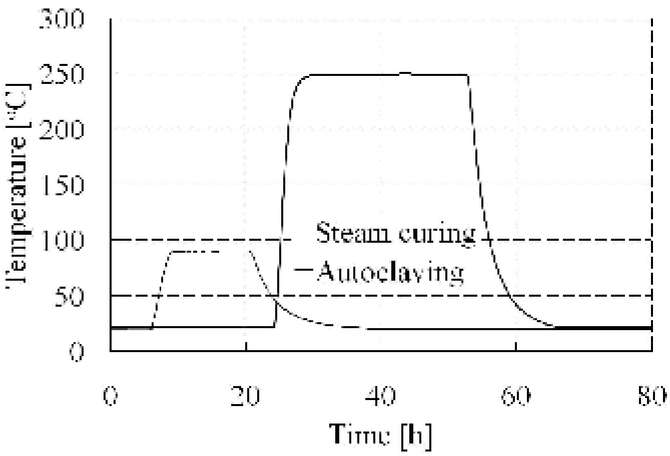

Fig. 2 Temperature versus time for the two curing conditions

3 Test results

The test results of the compressive and flexural strength of RPC with variable volume of steel and glass fibres and cured in three different conditions are presented in Fig. 3 and 4. The tensile strength at bending of each material was obtained by testing 6 beams (40x40x160 mm) in three-point bending test. 12 cubes (40x40x40 mm) were cut from the broken beams and tested for the compressive strength. In the case of water curing, specimens were examined after 28 days of setting. Steam cured and autoclaved specimens were tested after heat treatment was completed and the specimens were cooled down.

In materials without fibres content and cured in natural conditions, a compressive strength of about 200 MPa and flexural strength 11 MPa is obtained. Steam curing allows strengths up to 212 and 14 MPa, respectively, while autoclaving allows up to 268 MPa and 18 MPa. The addition of steel fibres allows a further increase of both compressive and flexural strengths. The highest values reached are 315 MPa for compressive strength and 27 for tensile strength at bending. These parameters were obtained for autoclaved composites containing 4% vol. (310 kg/m^3) of steel fibres.

The addition of tested glass fibres does not change the compressive strength of the material. However, increasing the fibres content enhances tensile strength at bending, depending on the curing conditions.

Linear progression of compressive and flexural strength versus steel fibres volume fraction can be observed for all studied curing conditions [27].

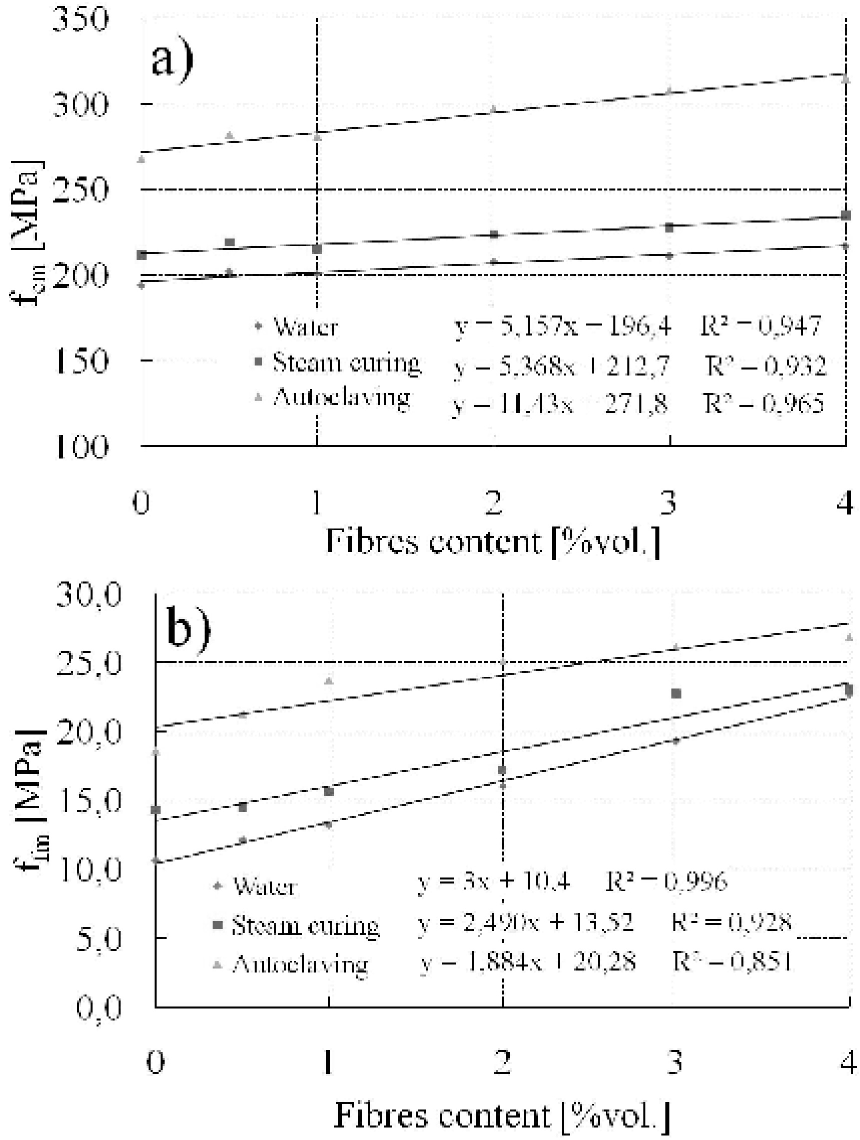

Fig. 3 Compressive strength (a) and flexural strength (b) versus steel fibres content in three different curing conditions

4 Microstructure of RPC

The influence of curing conditions and fibres content on compressive and flexural strength as well as deformability during bending can be explained by the microstructure formation of tested materials. There are at least three factors that permit ultra-high performance cementitious composites:

- very compacted microstructure of the CSH phase,

- very good adhesion of the CSH phase to mineral inclusions (grains of grounded quartz and quartz sand) and also to steel fibres,
- fill in voids in the microstructure of materials caused by crystallization of xonotlite and tobermorite during autoclaving.

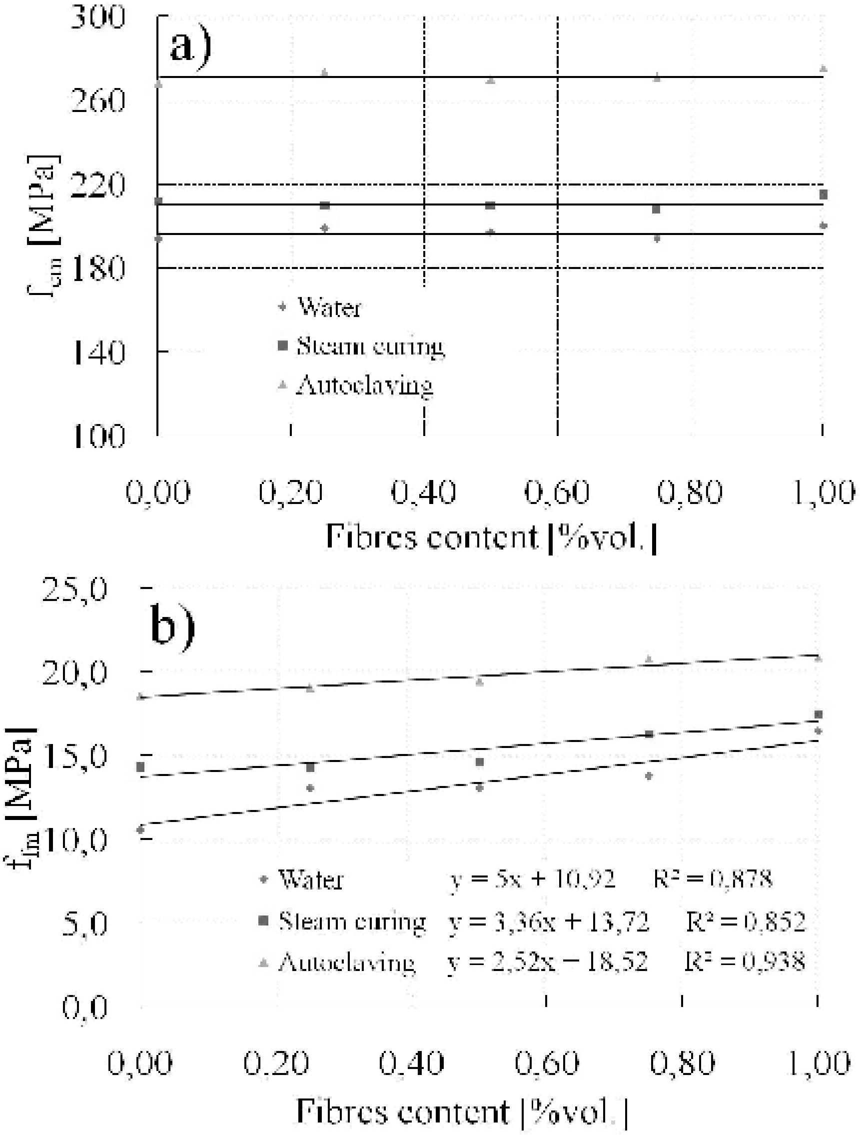

Fig. 4 Compressive strength (a) and flexural strength (b) versus glass fibre content in three different curing conditions

Obtaining a crystalline form of CSH phase is possible only during autoclaving. Therefore in composites cured at 250°C, the highest sealing of microstructure can be observed.

Fig. 5 shows the microstructure formation of the composites cured in three different hydrothermal environments. Very compacted microstructure in the CSH phase and its excellent adhesion to grains of cement (light inclusion) as well as to quartz grains (dark inclusion) can be observed in each case of curing conditions. Steel fibres with tightly sheathed products of cement hydration are presented on Fig. 5a and 5b. A similar situation concerning glass fibres is presented on Figs. 5c and 5d. Moreover Fig. 5f shows the high magnification of self-interlacing whiskers of crystallized minerals.

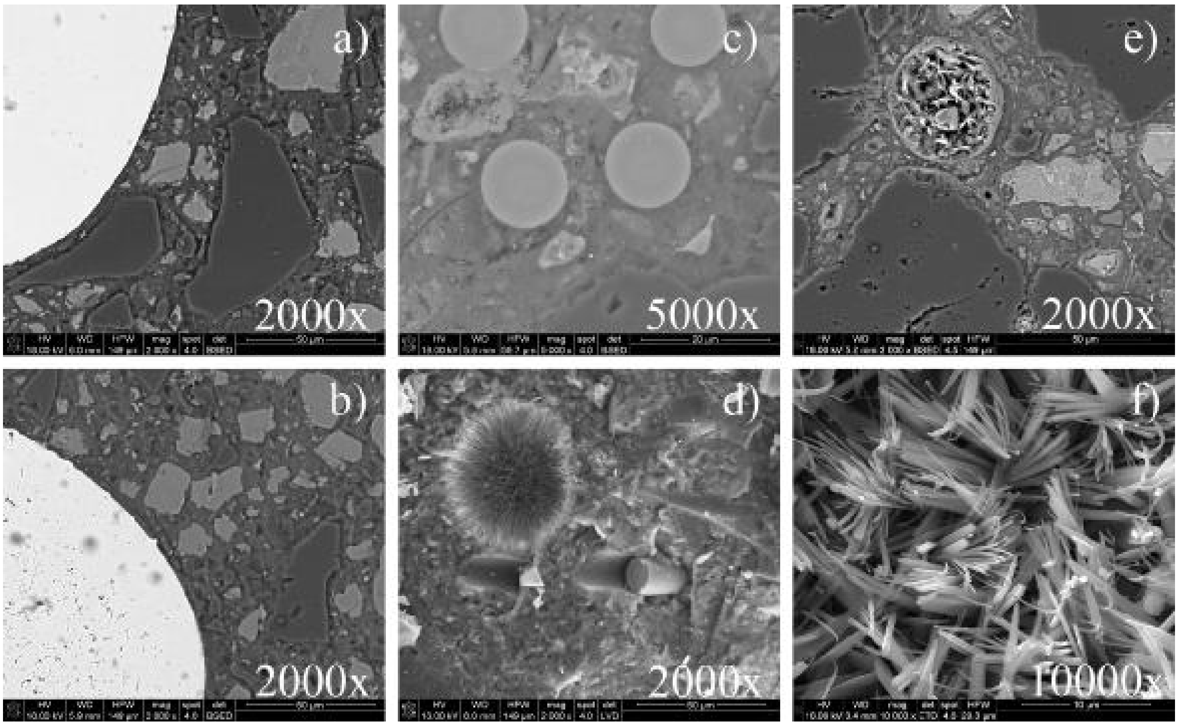

Fig. 5 Microstructure of RPC
a) cured in water with steel fibres, b) steam cured with steel fibres, c) autoclaved with glass fibres, d) fracture of autoclaved RPC with glass fibres, e) void in autoclaved RPC filled with whiskers of xonotlite and tobermorite, f) xonotlite and tobermorite crystals

5 Conclusions

It is possible to create ultra-high performance concrete using ordinary ingredients and traditional curing conditions. In materials without fibres content and cured in natural conditions, a compressive strength of about 200 MPa and flexural strength 11 MPa is obtained. Steam curing allows strengths up to 212 and 14 MPa, respectively, while autoclaving allows up to 268 MPa and 18 MPa.

The addition of steel fibres allows a further increase of both compressive and flexural strengths. The highest values reached are 315 MPa for compressive strength and 27 for tensile strength at bending. These parameters were obtained for autoclaved composites containing 4% vol. (310 kg/m^3) of steel fibres.

The addition of tested glass fibres does not change the compressive strength of the material. However, increasing the fibres content enhances tensile strength at bending, depending on the curing conditions. The highest increase (about 55%) can be observed for materials that were cured in water. In the case of steam-cured composites, the increase of flexural strength was equal to 22%, while for autoclaving only 12%.

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