Reactive powder concrete: material for the 21st century

D. Mestrovic, D. Cizmar & V. Stanilovic
Faculty of Civil Engineering, Zagreb, Croatia

Abstract

The most popular engineering material is concrete. It is used for buildings, industrial structures, bridges and dams. Every day the quality of concrete is improving, to achieve better characteristics, lower prices and to be environmentally acceptable. First the historical overview of concrete is given – from ancient civilizations to the 21st century. Then the making of reactive powder concrete (RPC), a composite material with compression strength up to 170 N/mm^2 is presented. The components for the RPC mixture are cement, fine aggregate, steel fibers, silica fume and super-plasticizer. They are carefully selected to achieve the optimal mixture. Detailed concrete mix proportions are given in the article. Preparation and testing of materials are made in the laboratory of the Faculty of Civil Engineering in Zagreb. As well as mechanical properties the durability parameters were also tested (gas permeability test, capillary water test). It is concluded that due to very high compression strength RPC can be used for big spans. RPC also has superb durability parameters such as abrasion resistance and reduced chloride permeability. These durability enhancements decrease maintenance costs and lengthen the service life of a structure. RPC is a material whose potential is yet to be identified.
Keywords: reactive powder concrete, durability.

1 Introduction

The first specimens of cement are around 12 millions years old. Reactions between limestone and oil shale during spontaneous combustion occurred in Israel to form a natural deposit of cement compounds. These deposits were characterized by geologists between 1960 and 1970. In 3000 years BC the Egyptians used mud mixed with straw to bind dried bricks. They also used

WIT Transactions on Engineering Sciences, Vol 57,
www.witpress.com, ISSN 1743-3533 (on-line)
doi:10.2495/MC070131

gypsum mortars and mortars of lime in the pyramids. The Chinese used cementitious materials to hold bamboo together in their boats and in the Great wall. The Romans used pozzolana cement from Pozzuoli, Italy near Mt. Vesuvius to build the Apian Way, Roman baths, the Coliseum & the Pantheon in Rome and the Pont du Gard aqueduct in south France. They used lime as a cementitious material. Pliny reported a mortar mixture of 1 part lime to 4 parts sand. Vitruvius reported a 2 parts pozzolana to 1 part lime. Animal fat, milk, and blood were used as admixtures (substances added to cement to increase the properties.)

Figure 1 shows Maxentius basilica built in the 4th century. During the middle ages these materials were not used until the beginning of the 19th century. In 1824 Joseph Aspdin of England invented Portland cement by burning finely ground chalk with finely divided clay in a limekiln until carbon dioxide was driven off. The sintered product was then ground and he called it Portland cement named after the high quality building stones quarried at Portland, England. The beginning of the Portland cement era incorporating modern composition was in 1828 when I. K. Brunel made the first significant engineering application of Portland cement, which was used to fill a breach in the Thames Tunnel.

Figure 1: Maxentius basilica.

In 1867 Joseph Monier of France reinforced William Wand's (USA) flowerpots with wire ushering in the idea of iron reinforcing bars (re-bar). In 1889 the first concrete reinforced bridge was built. Around 1950 concrete with a compression strength of 40 N/mm^2 was made. In 60 years of the 20th century the High Performance Concrete (HPC) was made. High performance concrete (HPC) is the name given to a class of materials that exhibits properties superior to those of conventional concrete. The superiority may lie in one or more of several attributes, such as strength, stiffness, freeze-thaw durability, or resistance to chemical attack. The properties are selected on the basis of the requirements of the particular application. Its compression strength ranges from the 50 N/mm^2 to 100 N/mm^2.

In the 1970's fiber reinforcement in concrete was introduced. During the 1980's super-plasticizers were introduced as admixtures. Around 1990 the Reactive Powder Concrete (RPC) first appeared. The strength of RPC goes up to 800 N/mm^2. While HPC is being used for bridges more and more, RPC is still very rarely used.

2 Components of RPC mixture

2.1 Introduction

This article presents the possibility of making RPC concrete with a compression strength of up to almost 200 N/mm^2. Four different mixtures are analyzed. First is the mixture of hybrid micro-fiber concrete, the others are composed of only one type of fiber.

2.2 Cement

As the class of cement increases the compression strength increases. For this mixture is selected the Portland cement (PC 55) with no mineral ingredients.

2.3 Fine aggregate

The aggregate that is used for the making of this mixture is quartz aggregate. Two fractions of this material are used, one with soil size of 0.125 – 0.25 mm, the other with 0.25 – 0.5 mm, effectively meaning that the maximal size is 0.5 mm.

2.4 Steel fibers

Two different types of steel fibers are used (shorter and longer fibers). Shorter fibers are 13 ± 2 mm long, with diameter 0.2 ± 0.02 mm. Minimal tensile strength is 2600 MPa. Longer fibers have curvature ends, their length is 40 ± 3 mm, diameter 0.5 ± 0.02 mm. Minimal tensile strength is 2600 Mpa. In both cases the high tensile fibers are used to achieve necessary ductility.

2.5 Silica fume

Silica fume is a pozzolanic additive, with specific area of 20 m^2/g.

Other parameters are:

- density	2.23 g/cm^3
- sieve residue 45 μm	5.6%
- pH value	8.44

www.witpress.com, ISSN 1743-3533 (on-line)

2.6 Super-plasticizer

Superplasticizer is primarily used to decrease the participation ratio of water in the concrete mixture. The chosen superplasticizer is based on policarbon-silate. It is brown fluid, dissolves in water and doesn't contain chlorides.

Other parameters are:

- density 1.064 kg/dm^3
- pH value 7
- alkalinity 0.31%
- viscosity on 20˚C 134 mPas

2.7 Compatibility of cement and super-plasticizer

Compatibility of PC 55 cement and super-plasticizer Glenium ACE 30 is one of the very important demands for achieving a good RPC mixture. Compatibility is measured by the change of consistency of concrete. To achieve proper treatment of concrete it must detain its characteristics for approximately 1.5 h for site application and 0.5 h for prefabrication.

Table 1: Ingredients per m^3 of RPC.

Mixture number	M1	M2	M3	M4
Steel fibers (kg/m^3) SF1 (40/0.5) SF2 (13/0.2)	 76 190	 228	 228	 234
Cement (kg/m^3)	720	955	720	980
Fine aggregate (kg/m^3)	230	239	230	303
Quartz sand 0,125-0,25 0,25-0,5 (kg/m^3)	 123 1112	 105 945	 123 1111	 105 965
Superplasticizer (kg/m^3)	30	35	31	40
Water (l/m^3)	190	215	190	209
Concrete properties temperature pores density consistency	 24˚C 5% 2,41 kg/m^3 140 mm	 25˚C 5% 2,35 kg/m^3 250 mm	 24,5˚C 5% 2,36 kg/m^3 190 mm	 26˚C 5% 2,306kg/m^3 220 mm

3 Experimental results

Compression and tensile strength measurement were conducted on 4 specimens with prismatic shape (40 x 40 x 160 mm). The specimens were 28 days old. First the tensile strength was measured, than the compression. Table 2 presents the experimental results for each mixture. Figures 2 and 3 show specimens after the tests.

Table 2: Experimental results.

	Flexure strength (mean) (MPa)	Compression strength (mean) (MPa)
M1	46.9	132.0
M2	42.8	155.6
M3	42.8	153.3
M4	48.8	174.8

Figure 2: Specimens after testing.

4 Gas permability test

Gas permeability is tested according to Croatian regulations EN 993-4. Specimens were cylindrical, with diameter and length 50 mm. They were taken from a prism 10 x 10 x 50 cm (first mixture). The specimens were put in a dry chamber until constant mass was achieved. The specimens were than cooled to room temperature, polished and coated with epoxy. A pressure difference of 3 bars wasn't detected which means that gas permeability is very low (none was detected).

Figure 3: Specimens after testing.

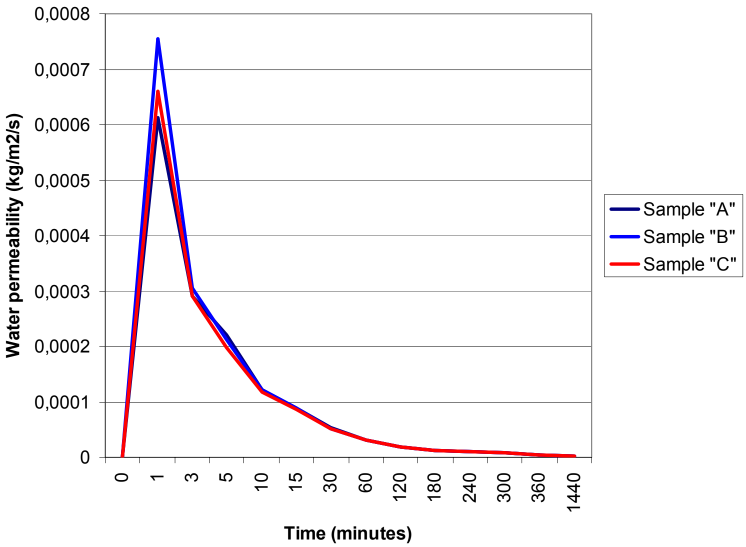

Figure 4: Capillary water test.

5 Capillary water test

Capillary water testing was conducted according to Croatian regulations HRN.U.M8.300:1985 in the laboratory of Civil engineering faculty in Zagreb on specimens 28 days old. The diameter of the specimen was 15cm and the height was 10cm. Before testing, the specimens are dried on 105˚C and then left for 2 days in the laboratory. Sealing putty was applied on one side. Specimens were than weighed.

Capillary water testing was made in intervals of 1, 3, 5, 10, 15, and 30 minutes after immersing in water, and then after 1, 2, 3, 4, 5, 6, 24 hours. Results show the linear proportion between the capillarity water and square root of time. Height of capillarity water could not be determined because it didn't cross the area sealed with sealing putty. Starting absorption capacity is for ordinary concrete after 10 min 0.25, after 30 min 0.17, and after 1 hour 0.10 ml/m^2/s. These results show (figure 4) that RPC has very little water permeability. Its absorption after 10 minutes is much less than that of ordinary concrete after an hour.

6 Conclusion

This article presents the possibility of making RPC concrete with a compression strength up to 180 Mpa. Due to the very high compression strength RPC can be used for big spans. RPC also has excellent durability parameters like abrasion resistance and reduced chloride permeability. This makes RPC an ideal material for bridges in the Adriatic coast because durability problems are primary related to the fact that the protective layer to reinforcement is rapidly being destroyed. High speed winds drift large amount of chlorides that destroy the bridge structure, primary arch and the columns. These durability enhancements provide RPC with decreased maintenance costs and lengthen the service life of a structure, which is vital for bridges in the Adriatic region.

References

[1] Candrlic, V., Concrete arch bridge over Bakar straits. *Proceedings for Conference of Croatian builders*, eds. V. Simovic, Cavtat, pp. 358-364, 2001.

[2] Jagar, A., High performance concrete, Faculty of civil engineering: Zagreb, 2003.

[3] Edward Nawy, G., *Fundamentals of high-performance concrete,* John Wiley & Sons: New York, 2001.

[4] Cizmar, D., Mestrovic D., Radic, J., “Arch bridge made of reactive powder concrete”, HPSM 2006, Ostend, 2006.

www.witpress.com, ISSN 1743-3533 (on-line)