Investigate national Study on Environmental Impact of Reactive Powder Concrete

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***Abstract*— This Reactive Powder Concrete (RPC) is an ultra-high strength, low porosity material with high cement and silica fume contents, steel fibers, low water-binder ratios and a new generation superplasticizer. With compressive strength in excess of 200 MPa, tensile strength of 20-40 MPa, and high workability, RPC can be used readily in a wide variety of structural applications, including bridges. It is ideal for prestressed applications which is one of the important benefits. This paper strongly states usage of different material and their impact on the environment. A copolymer of acrylic ester (CAE), a poly naphthalene Sulfonate (PNS) and a polymelamine sulfonate (PMS) are normally employed for the purpose. These admixtures are synthetic polymers. Compressive strength is one of the factors linked with the durability of a material. In the context of nuclear waste containment materials, the compressive strength of RPC is higher than required. An opportunity to improve the sustainability of this industry by further exploring the use of alternative materials. Reactive Powder Concrete (RPC) is a developing composite material that allows the concrete industry to optimize the material usage by generating economically benefits and helps the structure to become more strong, durable and sensitive to the environment. Furthermore, the RPC satisfactorily meets the requirement of practical application for Xiahou Bridge built with the RPC totally according to the calculation with finite element analysis software MIDAS/Civil. And the static loading testing result suggests that the design of the bridge meets the utilization requirements. Fly ash (FA), ground granulated blast-furnace slag (GGBS) and limestone powder (LP) are used to replace cement, and their effects on the properties of the designed UHPC are analyzed. The results show that the influence of FA, GGBS or LP on the early hydration kinetics of the UHPC is very similar during the initial five days, while the hydration rate of the blends with GGBS is mostly accelerated afterward. The durability characteristics of RPC in such applications become paramount for the success of the containment of the wastes. The adverse environmental conditions at the disposal site could attack the concrete barrier and results in degradation of the material. It is resistant against aggressive environmental conditions and extreme climatic conditions.**

Index Term—

***Index Terms*— Compressive Strength, Mechanical Properties, Reactive Powder concrete**

I. Introduction

RPC is composed of very fine powders (cement, sand, quartz powder and silica fume), steel fibers and superplasticizer. The super plasticizer, used at its optimal
dosage decreases the water to cement ratio (w/c) while improving the workability of the concrete. A very dense matrix is achieved by optimizing the granular packing of the dry fine powders. This compactness gives RPC ultrahigh strength and durability. Reactive Powder Concretes have compressive strengths ranging from 200 MPa to 800 MPa. Microstructure enhancement of RPC is done by heat curing. Heat curing is performed by simply heating (normally at 90°C) the concrete at normal pressure after it has set properly. This considerably accelerates the pozzolanic reaction, while modifying the microstructure of the hydrates that have formed. Pre-setting pressurization has also been suggested as a means of achieving high strength. The high strength of RPC makes it highly brittle. Steel fibers are generally added to RPC to enhance its ductility. Straight steel fibers used typically are about 13 mm long, with a diameter of 0.15 mm. The fibers are introduced into the mixture at a ratio of between 1.5 and 3% by volume. The cost-effective optimal dosage is equivalent to a ratio of 2% by volume, or about 155 kg/m^3.

It was also observed that RPC containing high volume ground granulated blast furnace slag (GGBFS) for replacement of silica fume has been producing a compressive strength of over 250 MPa after autoclaving which was a satisfactory mechanical performance. Additionally, the amount of silica fume was decreased with increasing amount of GGBFS.On conventional concrete, the flexural strength of fly ash plus glass powder decreases by 1% at 11% of glass powder percentage and thereafter it increases by 8% after 30% of the increase in glass powder after 28 days. In the scientific community, the development of innovative materials and methods aiming at extending the lifetime of both existing and new structures is mandatory for the sustainability of the construction sector. According to Ghafari et al. (2015), the partial replacement of silica fume and Portland cement by incorporating supplementary cementing materials (SCM) can be practical to produce UHPC with equivalent mechanical performance. Many industrial by-products like silica fume have been standardized as SCMs. However, these traditional SCMs are not always available in all regions and would be costly to transport. Hence, developing local alternative SCMs is of paramount importance (Omran & Tagnit-Hamou, 2016). Additionally, since the shortage of post-consumer disposal waste sites were one of the principal problems in most developing countries, regenerating and using waste product as a resource and prevent environmental pollution is the best mechanism. Moreover, these days, a new generation concrete called reactive powder concrete is under development as an ultra-dense mixture of silica fume, water, Portland cement, fine quartz sand, superplasticizer, quartz powder, and steel fibers. Compared to conventional and high performance concretes, reactive powder concrete mixtures provide better properties since they are optimized at the micro-scale level (Ahmad, Zubair, & Maslehuddin, 2015). On the other aspect, for environmental sustainability and enhancement of concrete properties, waste materials such as construction and demolition wastes and organic wastes have been introduced in the making of concrete.

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II. MATERIALS AND INVESTIGATION

2.1 MATERIALS

The characteristics of the constituents of RPC used in this study are described as follows,

(1) Cement: RPC normally uses either the Type II or Type V Portland cement as the cementitious material due to the consideration of moderate sulfate resistance and low hydration heat in order to enhance the flowability and the durability. Type II cement with of the fineness of 314 m2 /kg was used in this study.

(2) Silica fume: Imported micro silica was used. The content of SiO2 is about 95%, and its specific surface area exceeds 20000 m2 /kg with the particle size ranging from 0.67 to 5.02 µm. Basic properties examined by the ASTM C 1240 standard are shown in Table 1.

Table 1 Basic properties of silica fume

SiO_2	LOI	Passing through	Reactivity index (7 days)	Specific gravity
94.59%	0.97%	93.65%	98.47	2.22

(3) Quartz sand: The average size of cement grain is in the range between 10 to 16 µm and the maximum grain size in the range of 80 to 100 µm. In order to avoid its possible interference with the quartz sands in the formulation of an optimal compact skeleton of particle assembly, the minimum and maximum grain size of quartz sand are limited to 150 µm and 600 µm, respectively. Thus four different size grades, (600 µm), (300 µm), (150 µm) and (75 µm), of quartz sand were used. The average specific gravity is 2.57.

(4) Quartz powder: The purpose of using quartz powder in RPC is to activate its reactivity in the process of cement hydration. The optimal grain size that has the maximum of reactivity is in the range between 5 and 25 µm which is in the same size order of cement grain. Both belong to the same size level of solid constituents in the packing gradation of RPC. The grain sizes between 2.41 and 15.02 µm were used in this study.

(5) Steel fiber: Straight imported steel fiber with the diameter of 0.2 mm and the length of 16 mm was used. To avoid rusting in the ambient temperature, these steel fibers were plated by a thin layer of copper and had a golden surface.

(6) Superplasticizer (SP): Polycarboxylate based superplasticizer in liquid form was used to maintain good consistency and workability during the whole casting stage.

2.2 MIX PROPORTION

For RPC and normal weight concrete (NC) The major principles for a proper mix proportioning design of RPC include two aspects. The first one is to let the sizes and amounts of its solid constituents, such as cement, silica fume, four types of quartz sand and quartz powder, be graded to achieve optimum packing. The second one is to add a proper dosage of SP such that a proper flowability during the casting of fresh RPC can be maintained in order to achieve an optimal performance of RPC in terms of homogeneity and compactness. After carrying out a set of systematic tests, the resulting mix proportions of RPC were given in Table 3. The water/cementitious-materials ratio (W/C) is as small as 0.193. There is a significant amount of cement, silica fume, and quartz sand, which occupies 77.2% by weight of the total RPC constituents. The addition of 2% of steel fiber per volume increases the tensile strength and improves the resistance to cracking of RP. On the other hand, the mix proportions of normal concrete (NC) are given in Table 2, which follows the ACI Standard Practice 211.1. The NC was used either as the basic material to be retrofitted by the RPC or as the control set for the comparison with the performance of RPC.

Table 2 Mix proportions for normal weight concrete (NC) (kg/m3)

Label	W/C	Water	SP	Cement	Fineag-gregate	Coarse aggregate
NC	0.60	23 5	0.98	392	592	1044

III. EXPERIMENTAL PROCEDURE

Dry RPC components of cement, quartz sand, silica fume and quartz powder were mixed for 3 to 5 minutes with low-speed gear, then total pre-mixed water and SP were added and mixed for another 2 to 3 minutes to let the resulting paste obtain a proper consistency and flowability. The steel fibers are then spread into the paste and mixed for 2 minutes with middle-speed gear to finish the mixing of RPC. The fresh RPC was cast into cylindrical paper molds of 50 mm in diameter and 100 mm long and cured in an ambient laboratory environment for 24 hours. Afterward, these RPC cylindrical specimens were demolded and cured with two kinds of curing treatment: in a steaming chamber at a temperature of 85°C for three days; in an ambient temperature for three days. Then they were submerged in the saturated lime water until the day of testing. Normally, additional pressure was applied to the fresh RPC during setting with an elevated temperature of 90°C or between 250-400°C in order to improve its strengths [1-2]. But on account for the compatibility of material properties between the base NC member and retrofitting RPC as stated previously, the traditional RPC curing treatment was modified with a lower curing temperature of 85°C or an ambient temperature and without applied pressure.

On the other hand, two types of NC specimens were cast: cylindrical specimen for compressive strength test and beam specimen for flexural strength test as shown in Fig. 1(a). Three different sizes of cylindrical specimens were cast: φ70×200 mm, φ80×200 mm and φ100×200 mm according to the ASTM C 31 procedure. Three different sizes of beam specimens were also cast 130×150×500 mm, 140×150×500 mm and 150×150×500 mm following the procedure of ASTM C 78. All NC specimens were moist cured for at least 28 days. Meanwhile, two kinds of thin plate specimen of RPC were also cast as the retrofitting material: 10×150×500 mm and 20×150×500 mm. The outer circumferential layers of these two smaller sizes of cylindrical NC specimens of φ70×200 mm and φ80×200 mm were then cast by fresh RPC with a thickness of 15 mm and 10 mm, respectively, such that both of their final dimensions become φ100×200 mm, and then moist cured in ambient temperature. Similarly, the bottom surface of these two smaller NC beam specimens of 130×150×500 mm and 140×150×500 mm was bonded with RPC plate sheets of 20×150×500 mm and 10×150×500 mm, respectively, using an epoxy-based adhesive. Both of their final sizes also become the standard size of 150×150×500 mm for the flexural test.

The flowability test of RPC was conducted by the flow table method modified from the procedure of ASTM C 1437. This procedure was originally designed for the measurement of consistency of mortars expressed as mortar flow, defined as the percentage of the spread diameter of mortar sample after the table is dropped 25 times in 15 seconds over the original bottom diameter of truncated cone sample. For some of the high flowability of RPC, the numbers of drops may not be necessary. The compressive test of RPC and NC cylinders followed ASTM C 192 and C 617.

IV. COMPRESSIVE STRENGTH

RPC has higher compressive strength than HPC, as shown in Fig. 1. Compressive strength at early ages is also very high for RPC. Compressive strength is one of the factors linked with the durability of a material. In the context of nuclear waste containment materials, the compressive strength of RPC is higher than required.

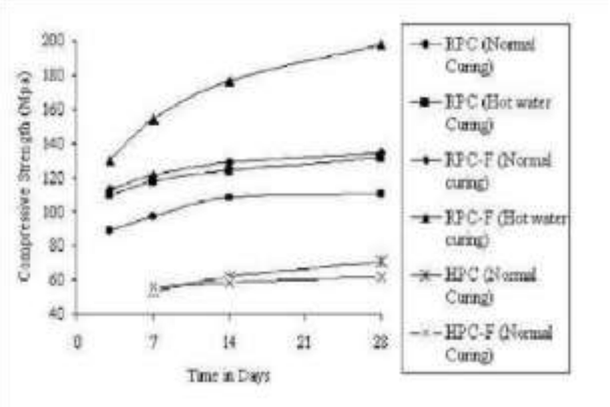

Fig 1: Compressive strength of RPC

The incorporation of fibers and use of heat curing was seen to enhance the compressive strength of RPC by 30–50%. The incorporation of fibers did not affect the compressive strength of HPC significantly.

One of the desires to identify the mechanical performance of the produced RRPC in this study was compressive strength evaluated by replacing different percentages of the proposed materials. The mean compressive strengths of three RRPC specimens produced from four categories (including control mix) were presented.

The first series of RRPC mix was developed by replacing the silica fume fully using 20% fly ash (FA) and 80% finely dispersed glass powder (GP). A maximum mean compressive strength of 59.41 MPa was observed after 28 days standard curing. On the other hand, in the second series of RRPC mix, 50% fly ash (FA) and 50% finely dispersed glass powder (GP) was employed to replace the silica fume fully. As shown in Figure 3, 14.25% and 5.36% rise in compressive strengths were observed after 14th and 28th days standard curing respectively compared to the early observed value after the 7th days of standard curing. Similarly, 3.31% and 14.53% rise of compressive strength was observed in the third series of RRPC mix that comprises 75% fly ash (FA) and 25% finely dispersed glass powder (GP) to replace silica fume fully.

V. FACTORS AFFECTING STRENGTH

5.1 Silica Fume Percentage

It is observed that the compressive strength tends to decrease as the silica fume dosage increases. The compressive strength is seen to fluctuate in the range of 15 % to 25% of silica fume regardless of water/binder ratio. As silica fume content increases, mix requires a more super plasticizer to disperse in fresh concrete.

5.2 Quartz Powder

Hydrated cement alone cannot help to elevate the strength of RPC, but other finer materials also contribute marginally. Quartz powder improves the filler effect in RPC mix. Addition of quartz powder produces the better result under accelerated curing condition than that of the normal curing condition. The results show that the addition of quartz powder increases the compressive strength by 20% under the accelerated curing condition.

5.3 Curing Regime

An adequate supply of moisture is necessary to ensure that hydration is sufficient to reduce the porosity to a level such that the desired strength can be attained. The compressive strength increased by 10% when cured in hot water as compared to normal curing. This indicates that curing temperature has a significant effect on the early strength development of RPC. The increased strength is due to the rapid hydration of cement at higher curing temperatures of 90°C compared to that of 27°C. Moreover, the pozzolanic reactions are also accelerated by the higher curing temperatures.

5.4 Compressive and tensile properties of RPC at elevated temperatures

Cube compressive strength decreases at 100 °C, increases at temperatures from 200 to 500 °C, and decreases at temperatures above 600 °C. Below 300 °C, the cube compressive strength of RPC increases as the fiber content increases, but decreases above 300 °C as the fiber content increases. The tensile strength of RPC with steel fibers decreases at temperatures below 200 °C, increases at temperatures ranging from 200 to 300 °C, and decreases at temperatures above 300 °C. 2% steel fibers prevent spalling and significantly increase mechanical properties.

5.5 Effect of pre-setting pressure

It is observed that the application of pre-setting pressure increased the compressive strength of the RPC about twice.

VI. CONCLUSION

The reactive powder concrete is ultra-high strength and high ductile composite material with advanced mechanical properties. Its properties like high ductility, lower water absorption and lower water permeability, high corrosion resistant etc can be very useful for many significant structures. Its mineral content optimization alone increases the cost a lot. Also, the east costly components of conventional concrete are eliminated. Hence the cost of construction is very high. So it cannot be used for normal buildings and structures.

It is used in structures which is of great importance and significance where the cost of construction doesn't matter and safety is a major concern. And hence its use is very limited. Mechanical properties of Reactive Powder Concrete indicate that better strength obtained when it replaced with Sugarcane Bagasse Ash than replacing Rice Husk Ash. Therefore, with the use of Sugarcane Bagasse Ash in partial replacement of cement in concrete, we can increase the strength of concrete with reducing the consumption of cement instead of landfilling and environmental lean.

REFERENCE

[1] Influence of superabsorbent polymer on shrinkage properties of reactive powder concrete blended with granulated blast furnace slag by Mo Jinchuan, Ou Zhongwen, Zhao Xuxin, Liu Jinming, Wang Yahui Construction and Building Materials 146 (2017) 283–296

[2] Mechanical properties of reactive powder concrete containing industrial and waste steel fibers at different ratios under compression by Ahmed Al-Tikrit, Muhammad N.S. Hadi Construction and Building Materials 154 (2017) 1024–1034

[3] Blast-resistant characteristics of ultra-high strength concrete and reactive powder concrete by Na-Hyun Yi, Jang-Ho Jay Kim, Yong Seok Han, Yun-Gu Cho, Jang Hwa Lee Construction and Building Materials 28 (2012) 694–707

[4] Effect of high temperature on reactive powder concrete by Mehmet Canbaz Construction and Building Materials 70 (2014) 508–513

[5] An analysis of the steam curing and autoclaving process parameters for reactive powder concretes by Tomasz ZdeB Construction and Building Materials 131 (2017) 758–766

[6] Microstructural analysis of RPC by Marcel Cheyrezy, Vincent Maret, Laurent Frouin Cement and Concrete Research, Vol. 25, No. 7. pp. 1491-1500.1995

[7] The composition of Reactive powder Concretes by: Pierre Richard, Marcel Cheyrezy Cement and Concrete Research, Vol. 25. No. 7, pp. 1501-1511.1995

[8] Compressive stress-strain relationship of steel fiber-reinforced reactive powder concrete after exposure to elevated temperatures by: Wenzhong Zheng, Haiyan Li, Ying Wang Construction and Building Materials 35 (2012) 931–940

[9] Effect of pre-setting pressure applied to mechanical behaviors of reactive powder concrete during setting phase by: Metin Ipek, Kemalettin Yilmaz, Mansur Sümer, Mehmet Saribiyik Construction and Building Materials 25 (2011) 61–68

[10] The effect of autoclave pressure, temperature and duration time on mechanical properties of reactive powder concrete by: Halit Yazıcı, Engin Deniz, Bülent Baradan Construction and Building Materials 42 (2013) 53–63

[11] Assessing drying shrinkage and water permeability of reactive powder concrete produced in Hong Kong by: C.M. Tam, Vivian W.Y. Tamb, K.M. Ng Construction and Building Materials 26 (2012)89

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