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Effects of Microsilica Percentage Amount on Structure and Compressive Strength of Reactive Powder Concrete (RPC)

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Abstract: Reactive powder concrete is a new kind of powerful concrete which is called so because of tiny powder and pozzolanic materials as well as a lot of hydraulically active materials used in it and it has been presented by two French scientists in 1994. The aim of this study is to measure the possibility of producing powder concretes using local materials used in Asaluyeh Region. By calculating cement amount, water ratio to cement and optimal percentage of super plasticizer in this article, we start constructing six mix plans with different percentages of microsilica (0, 10, 15, 20, 30 and 40). Results show that 15% mix plan has the highest bending and compressive strength in three conditions of producing regimes.

Key words: Reactive powder concrete, pozzolanic, super plasticizer, microsilica, production

INTRODUCTION

Common concrete is one of the popular materials used in construction that some problems such as low strength and life time to corrosion is due to penetration of chlorosulfuric ion; therefore, researchers started using a more strength full concrete named High Performance Concrete (HPC) as an alternative. Then, Ultra High Performance Concrete (UHPC) was planed and as involved persons in concrete science tried their best, the project led to producing RPC (Lee *et al*., 2007). Increase of compressive strength in columns, raises porting capacity of the column and causes a section decrease. In conclusion, for an assumed section with definite load, the amount of used steel decreases. This decrease in the amount of steel is about 1% per 70 kg/cm^2 increase in strength of concrete that a comparison of mechanical behavior in powder concrete with other available concretes can be shown in Fig. 1.

Literature review: In reinforced concrete beam, since porting capacity will be limited for a determined percentage of tensile reinforcements, only by a simultaneous increase of concrete strength and steel percentage, porting capacity can be increased. In other words, for a definite porting capacity, dimensions of the section can be decreased using high-strength concrete. In pre-stressed members, illegal stress at the time of transferring pres-stressed power followed by porting capacity increases by boosting strength of concrete at that time. Shell curves and structures that basically act in pressure and underground shell structures especially under impulse loads can in a highly effective way use high-strength concrete. To plan these concrete, the way of using, type and amount of used materials in obtained strength amount are highly effective. RPC has been remarkably used since 1990. Before, HPC was the most important and suitable option for HPC.

The first structure with RPC is a bridge in Sherbrooke Quebec that RPC concrete has been used in its planning and construction and this matter has caused a remarkable reduction of concrete sections in terms of dimension and weight (Blais and Couture, 1999) (Fig. 2).

The common used materials in producing RPC include Portland cement, quartz powder, microsilica, super plasticizer and steel fibers (Yunsheng *et al*., 2008). To have a low expense, fly ash and microsilica are used in addition to Portland cement. Preparing quartz also demands a high cost; therefore, natural aggregates with 3 mm and lower are used in powder concrete (Yunsheng *et al*., 2008). More exactly, mix plan used in powder concrete is described as:

- Water ratio to cement or cement materials is 15-25%
- Total amount of cement materials is 750-1400 K in m^2 (Type 2 cement by replacing different percentages of microsilica in 15-50% intervals)
- Quartz sand has measure of particles between 150-600 u

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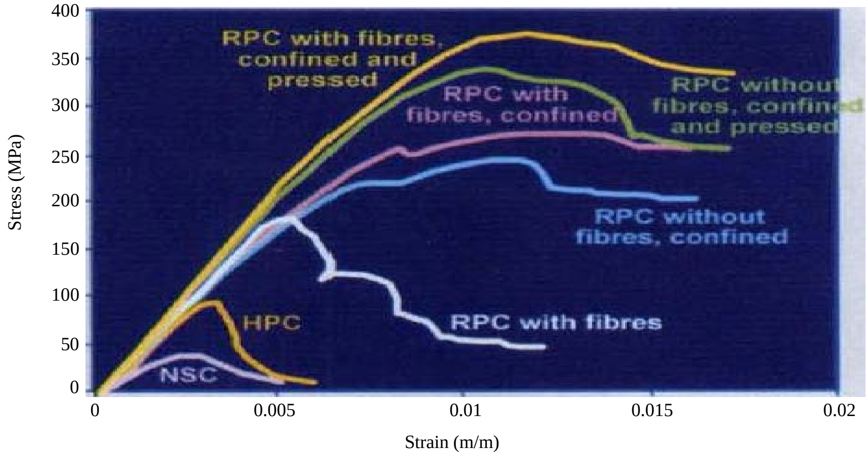

Fig. 1: A comparison of mechanical performance in powder concrete with other available concretes

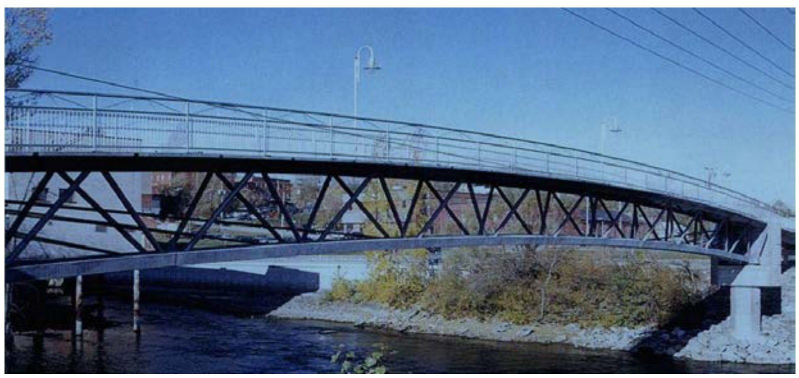

Fig. 2: The first structure in which powder concrete was used (Sherbrooke, Quebec)

- Natural sand passing from sieve 8
- Steel fibers in 2.5-10% intervals

Since, research and laboratory works about producing powder concretes have not been done in our country, along with this aim, producing special concretes by considering special climatic conditions in the south and appearance of special structures in Oil and Gas Industry projects as well as nuclear power station seems to be necessary. Therefore, the issues mentioned above are objectives for doing laboratory phase, studying the possibility of constructing and producing RPC by local materials of southern regions in our country. Cement materials used in this research include cement type 2 from Hormozgan Cement Company, sand from Siraf mine, microsilica from Ferroalloy industries in Azna, Hamadan and super plasticizer. Ether polycarboxylate base was used by a commercial name, Gleniume 110P. After doing six different mix plans with different percentages of microsilica (0, 10, 15, 20, 30, 40%), the optimal plan with replacement of 15% microsilica was known as the best plan which has the highest compressive and bending strength.

MATERIALS AND METHODS

Laboratory

Mix plan and features of used materials: In this research, a total cutie amount of cement materials was considered to be 1100 K in m^2 to be both determined as an average for interval of cutie changes in RPC and high strengths would be easily obtained. Then by considering water ratio to cement (0.2) along obtaining powder concrete plan, optimal super plasticizer additive amount was calculated. To obtain optimal plasticizer, 5 plans of mixing cement paste with different percentages of plasticizer (1.5, 1.8, 2, 2.3, 2.5) were produced and the time of passing from funnel for half liter cement paste was calculated by Marsh cone then we drew the diagram. In the diagram of logarithm based on percentage of using super plasticizer when the internal angle of diagram's break becomes 140+1 that percentage will be the optimal point of super plasticizer that according to the diagram optimal point is 2%. Based on what was mentioned above, mix plan of this research will be mentioned in Table 1.

determination of a suitable production method: According to the carried out researches related to planation and production of powder concrete, different methods have been used for producing the concrete (Lay, 1990; Orgass *et al*., 2004; Sadrekarimi, 2004; Cwirzen *et al*., 2008; Bentz *et al*., 2001; Atkins, 2003; John, 1998; Kosmatka *et al*., 2002). These methods include usual production (20°C water), thermal production (90°C water) and autoclave production (evaporation with 163-190°C and 560-1190 kPa). In this research along the matter that powder concrete must be produced by the minimum amount of energy, therefore, among the above methods, the method of production in a bathroom with 90°C water was selected:

- 1 day in mold
- 1 day in 20°C water
- 3 days in 90°C water

Doing the tests: After presenting research mix plans that have been mentioned in Table 1, we start producing concrete; and after doing Rheological test via Mini Flow Slump, we evaluate flowability of concrete; then we pour excess of it in cube molds (5×5×5 cm) for doing compressive strength test and in prismatic mold (4×4×16 cm) for doing bending strength test. After that the maximum plan of strength is determined, we make a cylindrical sample of this plan and to scrutinize mechanical behavior it is put under compressive test and studying deformation (Universal machine), so that elasticity module of optimal powder concrete would be calculated and at the end, plans 1, 3 and 5 which as representatives of six plans are used and based on differences of these three plans in strength and microsilica level have been selected and put under infrastructural tests including Scanning Electron (SEM) and Energy Dispersive analysis (EDS).

Table 1: Plans of powder concrete mixture in this research (amounts based on kg/m^3)

Water to sement materials	Water to cement	Cement	Microsilica	Water	Super plasticizer	Sand
0.2	0.20	1100	-	220	22	1013
0.2	0.22	990	110	220	22	977
0.2	0.23	935	165	220	22	958
0.2	0.25	880	220	220	22	940
0.2	0.28	770	330	220	22	904
0.2	0.33	660	440	220	22	868

RESULT AND DISCUSSION

Rheological examination: According to flowability of reactive powder concretes, studying amount of this flowability is used by small slump test which is used for self compacting mortar (Ramachandran, 1995) in this research. Based on EFNARC standard, mortar opening for about 24-26 cm is an acceptable amount for obtaining self compacting mortar. But in RPCs because of high cohesion among seeds, there is no possibility for separation of particles; therefore amount of opening more than the above limitation can also be acceptable.

According to Rheological test results which have been presented in Table 2, increase of microsilica has caused a decrease in powder concrete flowability. The main reason for this issue is some free water molecules surrounding around microsilica particles in cement paste structure.

Mechanical test: According to available matters in tests' processes, different samples were produced from powder concrete mix plans for studying mechanical

Table 2: Results of small slump flow test

Plan number	Average of opening diameter (cm)
1	32.5
2	30.0
3	29.0
4	28.0
5	25.0
6	25.0

Table 3: Results of compressive and bending tests (based on MPa)

	Production type					
	In usual water				In boiling water	
	Compressive strength		Bending strength			
Plan number	7 days	28 days	7 days	28 days	Compressive strength (5 days)	Bending strength (5 days)
1	54.9	67.1	10.1	13.6	80.8	17.8
2	66.5	75.4	13.7	15.4	94.9	22.2
3	73.4	81.8	15.0	17.5	101.9	23.4
4	63.5	71.6	12.2	14.9	93.3	22.1
5	53.1	65.3	8.9	11.8	85.5	20.5
6	50.2	59.5	7.8	10.4	83.7	19.7

behavior of these materials. Compressive and bending tests were used, since they are popular as the most important mechanical tests. After determination of maximum plan of strength, cylindrical sample was made from this plan and was put under compressive test and study of deformation to study mechanical behavior, so that elasticity module of optimal powder concrete would be calculated. Results of mechanical tests have been presented in Table 3.

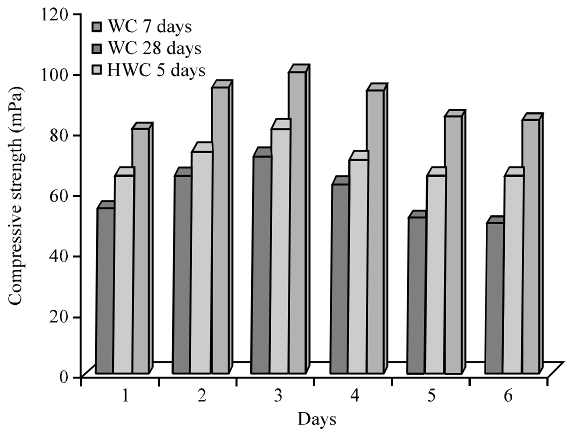

Fig. 3: Compressive strength of powder concrete samples under different productions (WC = Usual production, HWC = Production in hot water 90°C)

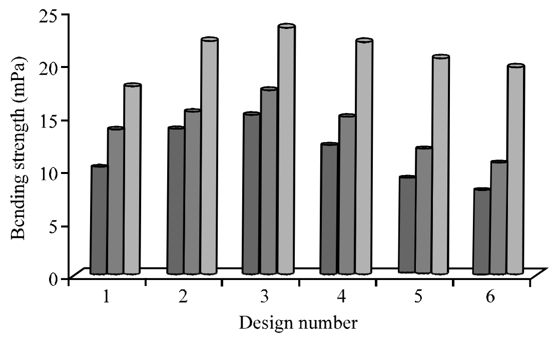

Fig. 4: Bending strength of different plans of powder Concrete in Different ages and productions (WC = Usual production, HWC = Production in Hot water 90°C)

According to Fig. 3 that explains a comparison of compressive test results in different production methods and different ages of production, strength maximum among plans, a plan having 15% microsilica (plan 3) has been obtained. With due attention to obtained results of Table 3 and comparing them, we get that plans having 10 and 15% microsilica (respectively plans 2 and 4) in condition of production in hot water have closer results to each other and the reason for this matter is boosting pozzolanic operation of microsilica under heating.

Also according to increase of microsilica mass in average and high amounts of cement replacement (20, 30, 40%), as inactive silica increases in paste matrix, powder concrete strength in both usual production and heating production decreases. In Fig. 4, the way of bending strength changes in powder concrete with a change in microsilica amount, age of samples and type of production have been shown. Along obtaining Elasticity module (E) with optimal plan, results of compressive test with controlled strain have been presented in Fig. 5.

Table 4: Feature strength and elasticity module of optimal plan (plan 3) and usual concrete plan

Plan name	Feature strength (mPa)	Rounded module (mPa) before being module	Elasticity elasticity rounded (GPa)
Usual concrete (C28)	28	25154	25.0
Powder concrete	100	40527	40.5

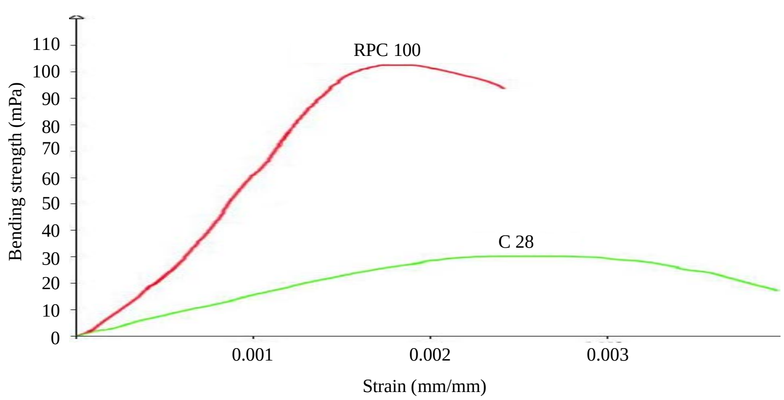

Fig. 5: A diagram of mechanical behavior in powder concrete sample of optimal plan (plan 3) compared with usual concrete sample (28 mPa)

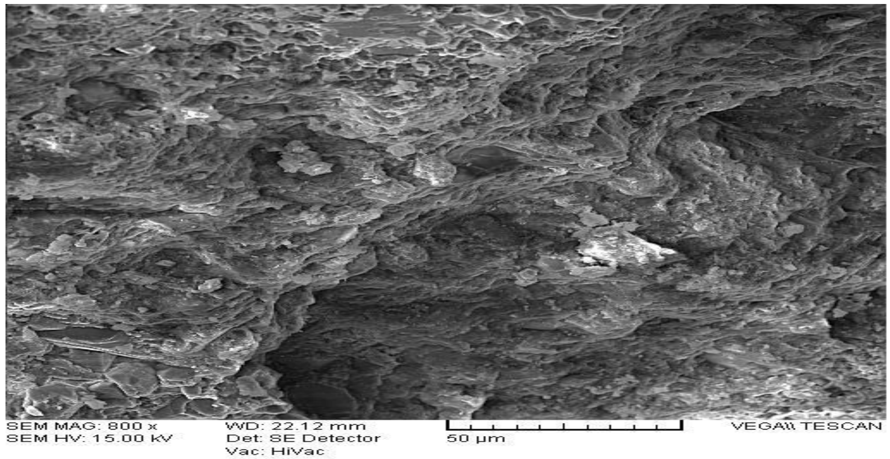

Fig. 6: A substructure of the 28 day basic plan under usual production (portlandite crystals in the left corner of the picture is clearly obvious)

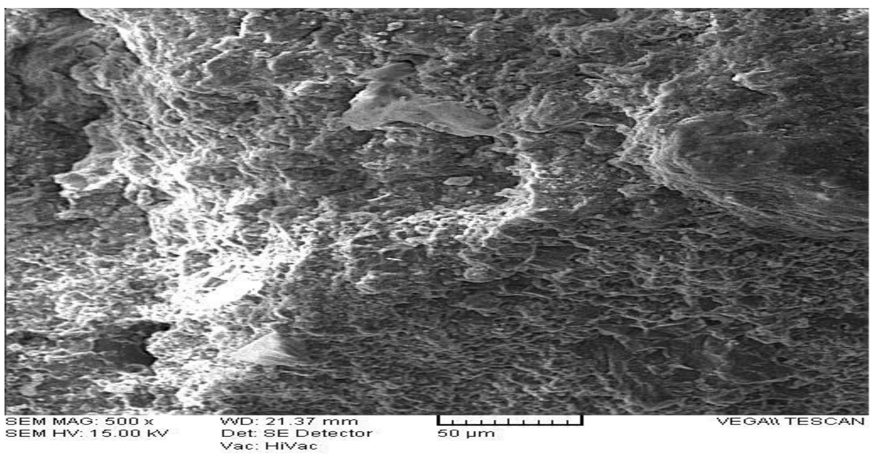

Fig. 7: Infrastructure of basis plan under heating production (producing amounts more than silicate-calcium gel (Sio_2) Ca in hydrate and creation of a compact structure from results of producing RPCs) (Magnified 500 times)

According to Fig. 5, we know that powder concrete is wet and fragile compared with usual concrete. Compressive strength results of the feature and elasticity module obtained from compressive test with controlled strain will be mentioned in Table 4.

Infrastructural study: Both SEM and EDS tests as infrastructural tests were done on obtained samples from different plans of powder concrete.These tests were only carried out on three plans as representatives of six plans (plans 1, 3 and 5). Creating a suitable environment for pozzolanic setting and flowability was mentioned as the main reason for improvement of infrastructure and strength of concrete samples under heating production. According to this matter and with comparison of Fig. 6 and 7 that respectively show infrastructure of basis plan (plan 3) under usual and heating production, we see that heating production leads to higher amounts of C-S-H Gel (Fig. 6 and 7).

Figure 8 and 9 which have been obtained from analysis results of energy differentiation show a comparison of Ca (Sio_2) in C-S-H gel structure available in matrix of RPC. As cleared out, C.S ratio in plan sample (3) has a remarkable increase compared with the sample without microsilica (plan 1).

When high amounts of microsilica are used in matrix, a remarkable part of these particles have only a filler role and not only they don't produce C-S-H gel with high strength but also by agglomeration with each other, they cause creation of weak points with low strength in matrix.

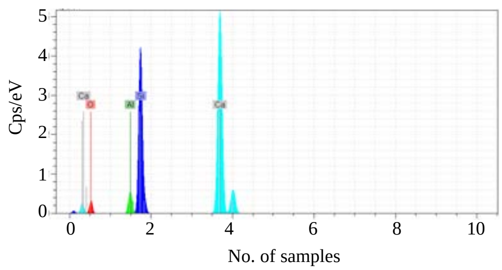

Fig. 8: C.S ratio in the paste available in plan 1 is equal to 1.9 which shows presence of higher amounts of type III gel C-S-H in powder concrete matrix

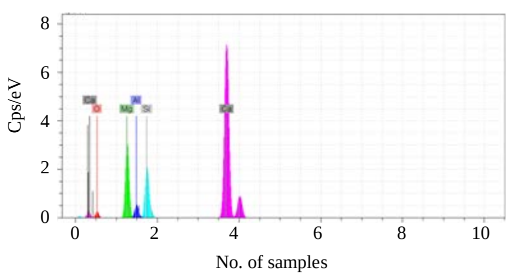

Fig. 9: C.S ratio in the paste available in plan 3 is equal to 3.5 which shows presence of higher amounts of Type I of C-S-h Gel in matrix of powder concrete

Therefore, strength of powder concrete plans decrease as microsilica amount decreases compared with optimal plan.

CONCLUSION

According to obtained results from this research that have studied possibility of producing local powder concrete in the south of country, the issues will be explained briefly as:

- With increase of microsilica replacement, opening diameter of flow in Small slump Test will decrease
- Strength maximum among plans has been obtained in the plan having 15% microsilica (plan 3)
- Plans with 10 and 20% have closer results in heating production condition
- Powder concrete strength has decreased as microsilica amount increased in both usual and heating productions
- Elasticity module of powder concrete becomes much more than usual concrete. Additionally, powder concrete has a highly fragile feature that for solving this problem, steel fiber must be used for producing this concrete
- Carried out infrastructural study shows that under heat production cause improvement of porosity structure and also improvement of doing pozzolanic reaction is saturated via activating silica particles with surface bonding

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