Comparative Investigations on Reactive Powder Concrete with and Without Coarse Aggregate

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Abstract. Crushed dolomite with a nominal size of 8 mm and fine quartz sand with a nominal size of 2 mm were used to produce reactive powder concrete (RPC) in this study. The compressive strength is comparable to that of standard RPC with a maximum aggregate size of less than 0.6 mm. The use of crushed dolomite modified the mixing process and mechanical properties and it was easier to fluidize and homogenize RPC that contained coarse material. The mixing time can be reduced compared to standard RPC. Under compressive, tensile, and flexural stresses, both RPCs behaved similarly, with the exception of a slightly differing modulus of elasticity, which was connected to the stiffness of the utilized aggregates. The results showed that at normal curing conditions, the locally available materials produced RPC with compressive, tensile, and flexural strengths of 134.3, 11.95, and 27.75 MPa, respectively. The study also confirmed the impact of fine aggregate type content and silica fume percentage on compressive, tensile, flexural strengths of RPC and drying shrinkage. Drying shrinkage of RPC including crushed dolomite was reduced because to the decreased paste volume fraction and the impediment of the stiffer crushed dolomite. Additionally, the durability performance was improved in terms of absorption and water permeability, giving ideal use in aggressive environments and effective for corrosion resistance.

Keywords: Reactive powder concrete · Mechanical properties · Autogenous Shrinkage · Silica Fume

1 Introduction

Reactive powder concrete (RPC) is a relatively new advancement in concrete technology. RPCs are cement-based materials with a low water-to-binder ratio (w/b) that have extremely high compressive strength, tensile strength, ductility, and durability, making them ideal for a variety of civil engineering applications [1]. Its compressive strength can exceed 150 MPa depending on its composition and treatment temperature [2, 3]. Richard and Cheyrezy [2] advised that the granular skeleton be optimized, the cementitious matrix be densified by lowering the water to binder ratio and post-set heat treatment, and coarse

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aggregates be removed. According to [2] one of the main reasons of micro cracking in the interfacial zone is the difference in mechanical and thermal characteristics between aggregate and cementitious matrix, and the length of micro cracks is related to aggregate grain size. As a result, aggregate grain size should be kept at 0.6 mm. The larger the aggregate surface to be surrounded with cementitious paste, the smaller the aggregates. In reactive powder concrete, this results in a large paste volume, which is required for manufacturing. Cement concentration varies widely between 600 and 1000 kg/m^3 [4, 5], indicating some drawbacks in concrete characteristics, such as excessive drying shrinkage. Reactive powder concrete has a high shrinkage rate due to its low water-to-binder ratio (w/b) and high binder content, especially at early ages. High early-age shrinkage can result in early-age cracking, compromising serviceability, durability, and aesthetics. Due to the refinement of the pore structure, silica fume was shown to dramatically increase drying shrinkage [6, 7].

The fibers enhance ductility and mechanical strength in concrete [8–11], minimize plastic shrinkage, and increase resistance to the room temperature effect [12].

In this work, experiments show that RPC with coarse aggregate can achieve the compressive strength of normal RPC. The behavior of RPC with and without coarse aggregate during the mixing process, as well as the properties of the RPC in the fresh and hardened states, were studied.

2 Materials and Methods

2.1 Materials

The components used in the preparation of RPC mixes are ordinary Portland cement, fine aggregate, coarse aggregate, silica fume, super-plasticizer (SP), water and fibers. Below is the description for each constituent.

The Portland cement used was CEM I N52.5, which has a mean particle sizes of 15 μm and a compressive strength of 53.8 N/mm^2 after 28 days. Cement's chemical compound compositions were; C3S 57.7%; C2S 18.7%; C3A 0.2%; and C4AF 15.3%. The details of cement utilized in this investigation are given in Table 1. Silica fume (SF) is a noncombustible amorphous material extracted by-product of the silicon and silicon alloys industries. The details of the silica fumes used in this analysis are described in Table 1. Only fine quartz sand in the range of 0.125 to 2 mm was utilized as fine aggregate in the first RPC group. Crushed dolomite splits with grains ranging from 5 to 8 mm were utilized as coarse aggregate in the second RPC group, with fine quartz sand as fine aggregate.

RPC heavily relies on superplasticizers (SP), which improve workability without requiring a lot of water. The SP included in this study is commercially available as Visco Crete −3425 and can be satisfied according to the ASTM/C/494, as G and F types [13].

The steel fibers employed in this experiment had a diameter of 0.2 mm, a length of 13 mm, a density of 7.85 T/m^3, and a yield stress of 289 MPa. A drinking water has been used throughout the mixing and healing operations of all RPC mixes investigated in this study.

Table 1. Silica fumes, quartz powder, and cement properties were used in this research.

Chemical compositions (%)	**Cement**	**Silica Fume**	**Quartz Powder**
CaO	61.09	-	-
SiO_2	21.58	96.02	97.0
Al_2O_3	4.94	1.01	0.17
MgO	1.65	0.18	-
Fe_2O_3	3.56	0.52	0.56
TiO_2	0.45	-	-
SO_3	3.22	0.26	-
Physical properties			
Specific surface area/Particle size	3,300 (cm^2/g)	170,000 (cm^2/g)	1–45 mm
Specific Gravity	3.15	2.20	2.85
Color	Light grey	Dark grey	Milky white
Loss of Ignition (LOI)	2.60	1.10	-

2.2 Mixture Proportioning

The experiment involves the creation of six RPC mixes (two groups): the 1st group is coded by (MF) which consists of three RPC mixes using fine quartz sand with a particle size of 2 mm only. The other three mixes of RPCs (2nd group) have been prepared using fine quartz sand and coarse aggregate with a particle size range of 5 to 8 mm and it's coded by (MC). All of these RPC mixes containing 157 kg/m^3 of steel fibers.

The cement content in these RPC mixes was 730 kg/m^3, as shown in Table 2. Table 2 shows the percentages by weight of cement for silica fume, fine aggregates, quartz powder, super-plasticizer, and water. For each cement content, three silica fume ratios of 0%, 15%, and 25% were utilized. According to Ju et al. [14], increasing the amount of silica fume in RPC enhances its compressive strength and compactness. The amount of the super-plasticizer was selected based on Lee's analysis [15] to be 4% of the cement weight. For all six mixes used in this study, the water cement ratio was kept constant to be 0.19. It worth mentioning that according to Richard and Cheyrezy [16], the water-cement ratio (w/c) was recommended to be between 0.17 and 0.19 for fibered RPC. According to Zheng et al. [17], 2% steel fiber content greatly improves mechanical qualities, with higher content having minimal effect. Each RPC mixture's constituent weights needed to form one cubic meter were computed. Mixes were created using an absolute volume method.

Table 2. Components of the RPC mixes used in this research.

Mix No.	Cement (kg/m^3)	Mix proportions (ratios by weight of cement)						*Stf* (kg/m^3)
		Fs	**Cs**	**SF**	**Qp**	**SP**	**w/c**	
MF1	730	1.75	0	0	0.3	0.4	0.19	157
MF2	730	1.57	0	0.15	0.3	0.4	0.19	157
MF3	730	1.44	0	0.25	0.3	0.4	0.19	157
MC1	730	0.72	1.08	0	0.3	0.4	0.19	157
MC2	730	0.65	0.97	0.15	0.3	0.4	0.19	157
MC3	730	0.60	0.90	0.25	0.3	0.4	0.19	157

Fs: Fine sand, Cs: Coarse sand, SF: silica fume, Qp: quartz powder, SP: superplasticizer, w/c: water to cement ratio, Stf: steel fiber.

2.3 Specimens Preparation

Using a 15-L pan concrete mixer, a mixing process was conducted. The components of each mix were carefully weighted to assure the accuracy of the findings. The SF and fine sand were applied to the cement and combined until a uniform mix was achieved. Half of the superplasticizer was dissolved in a half quantity of water and applied to the mixture for 2 min. After which, the second half of SP and water was used, giving a homogenous mixture. For the third step, all components were mixed at a constant rate for 1.5 min. Steel fibers were added at the final stage to be mixed for one minute at a speed of (285 ± 10 rpm).

For each test and age, an average value of three samples was recorded. The investigated tests included slump, density, compressive strength, modulus of elasticity, tensile strength, flexural strength, drying shrinkage, water absorption, and water permeability. The dimension of samples was: i) 50 mm cubes for density, water absorption and compressive strength tests; ii) 40 × 40 × 160 mm for the flexural test; iii) cylinder samples with a diameter of 50 mm and a height of 100 mm for elastic modulus and tensile strength tests; iv) (25 × 25 × 285) mm prisms for determination of length change; v) 100 mm cubes for water permeability test. Table 3 shows the age (s) conducted for each test. The compressive strength cubes were also used for density tests. Therefore, the total number of samples taken for each mix (considering that some samples were tested at two or three ages) was 30, in which for each mix, nine samples were molded for compressive strength test, three for modulus of elasticity, six for two ages of tensile strength, six for two ages of flexural strength, three for length change (shrinkage), three cubes for absorption test, and three for permeability as shown in Table 3.

Samples were mechanically compacted for 30 s after casting on a vibrating table. To avoid over-consolidation and isolation of the fibers from concrete, the vibration period was held to a low level. The samples were covered in a heavy plastic sheet after casting for 24 h before being demolded. After that, the specimens were cured for 28 days in a water tub at room temp (around 23 °C). All tests were performed 24 h after the curing process was completed.

2.4 Testing Methods

To assess the mechanical and durability characteristics of the RPC, a number of tests were performed on fresh and hardened samples. The flowability of the RPC mixtures was determined using an ASTM C-1437-15 [18]. The density was determined by weighing air dried 50 mm cubes after demolding them, then dividing the weight by the volume of the specimen. The standard method test (ASTM C109/C109M-20b) [19] was used to test the compressive strength of hardened mortar. A 40% of the expected concrete compressive strength was recorded during the test of the cylindrical specimens of (50 × 100) mm to measure the static elastic modulus as per ASTM C-469 [20]. Concrete's indirect tensile strength is a key factor in crack investigations and, as a result, in predicting concrete durability [21]. The tensile strengths of cylindrical concrete samples were measured using the standard method test suggested in ASTM C496 [22]. The ASTM C293 standard [23] was utilized to calculate the flexural strength of the simple beam loaded at mid span. The water absorption test was performed on 50 mm cube specimens at a 28-day age as per according to ASTM C642 [24]. The German's water permeability testing (GWT) manual [25] is followed while testing the water permeability of modified RPC. ASTM C490-00a [26] was used to change the length of the test specimens.

3 Properties of Fresh Reactive Powder Concrete

A slump test was performed after the mixing process was completed to identify some parameters of the fresh RPC mixes. Table 3 shows that both types of RPC met the requirements for self-compacting concrete and that there was no significant difference between them and conventional RPC. After 3 min of lifting the slump cone from the flow table, the average values of two perpendicular diameters of flowing concrete were measured. Table 3 lists the flow test results for all RPC mixes in terms of diameter. In general, the flow values ranged from 180 to 260 mm, as shown in Table 3. The addition of steel fibers affects the workability of RPC, giving a greater loss of workability. This could be attributed to an increase in the specific surface area resulting from the high content of steel fiber [27]. Furthermore, the steel fibers were uniformly dispersed around the matrix and served as a skeleton, preventing the flow of fresh concrete [28]. As demonstrated in [29–31], employing fillers to replace cement can considerably improve the workability of concrete while maintaining the same water and superplasticizer ratios. Due to the very low w/b-ratio and the very high fineness of silica fume and quartz powder the viscosity of the RPC is obviously higher than that of conventional RPC. The results showed that the existence of fine crushed dolomite and silica fume increases the workability of RPC mixtures. Mixes with fine crushed dolomite and 25% silica fume, showed relatively better workability and easier casting capacity compared with those without fine crushed dolomite and silica fume contents. Because of its circular particle form, silica fume improves the fluidity of the mix.

Results shows the RPC mix with a slump flow of more than 250 mm estimated after mixing. This indicates that such concrete can be pumped and utilized in high-rise building construction [32–35].

Table 3. Properties of RPC mixtures.

Group	Mix No.	Slump (mm)	Density (kg/m^3)	*% Ra*	*Pw* * 10^{-4} (mm/s)	*% Shrinkage At 60 d*
				28 d	**28 d**	
G1	MF1	180	2570	0.46	1.11	0.069
	MF2	193	2578	0.44	1.10	0.074
	MF3	218	2587	0.41	1.08	0.078
G2	MC1	220	2558	0.47	1.13	0.068
	MC2	245	2566	0.46	1.11	0.072
	MC3	260	2576	0.42	1.09	0.075

Ra: Water absorption ratio, Pw: Water permeability.

4 Mechanical Properties of Hardened Concrete

4.1 Density

According to the density values in Table 3, the results showed that densities of the RPC mixes ranged from 2570–2587 kg/m^3 for no fine crush dolomite to 2558–2576 kg/m^3 for those of fine crush dolomite. The reason for this difference is that the RPC mixes used in this study had various components. The addition of pozzolanic admixture also increases density by reducing capillary voids and micro cracks due to the chemical reaction of these components with calcium hydroxide. RPC mixes with silica fume have greater density values, which is owing to its ultra-fine particles, which operate as a good filler, according to the results. Increasing the cement content raises the density value despite the presence of silica fume and steel fibers. Cement is made up of microscopic particles, and any increase in their quality causes the density to rise. Steel fibers are used in RPC mixes, and the addition of these fibers results in a higher mix density due to the high density of steel fibers.

4.2 Effects of Silica Fume on Mechanical Strength and Drying Shrinkage of RPC

The influence of silica fume and fine aggregate type on RPC compressive, tensile, and flexural strength at 7 and 28 days was shown in Figs. 1, 2 and 3. It is clear from the results of the two groups, with and without fine crushed dolomite (where the silica fume is added at 0%, 15%, and 25% of the cement weight, respectively), that adding silica fume increases the mechanical strength. The rise is proportional to the amount of silica fume added. This is due to the ultrafine particle filler effect as well as the extra pozzolanic reaction. It is obvious that increasing the SF from 0 to 15% has a greater impact on the outcomes than increasing it from 15% to 25%. For example, the addition of 15% SF increased compressive strength by about 44 and 46%, tensile strength by about 26 and 24%, and flexural strength by about 35 and 30% for 28 days for the RPC with and without fine crush dolomite, respectively. However, such an effect was increased by about 18 and 19% for compressive, 19 and 18% for tensile, and 14 and 17% for flexural strength when increasing silica fume from 15% to 25% for the RPC with and without fine crush dolomite, respectively.

The compressive strength to tensile splitting strength ratio (fcu/fct) for the examined mixes with and without fine crush dolomite, respectively, varied from 9.9 to 11.25 and 9.4 to 11.19, while the compressive strength to flexural strength ratio (fcu/fb) ranged from 4.4 to 4.8 and 4.1 to 4.7.

RPC has a larger elastic modulus than regular concrete with the same aggregate type, according to theory. Its size is determined by the aggregate type and paste volume proportion. RPC without coarse aggregate, for example, usually contains quartz sand less than 1 mm. It has a modulus of elasticity of 42 GPa, which is lower than RPC with fine crushed dolomite (55 GPa).

In a temperature and humidity controlled environment, all prism specimens are permitted to shrink freely throughout the shrinkage test. Once a day for 60 days, the change in their length is recorded. All specimens' lengths have been shortened due to shrinking. The initial shrinking of all mixes is extremely high during the first several days. The shrinkage is continuing, but at a slower pace. The shrinking change is extremely small during the second month of testing. The shrinkage values at the end of the test are reported in Fig. 4a for comparison among the six mixes. It has been observed that as the silica fume is introduced, the shrinkage increases. As seen in Fig. 4b, shrinkage is associated with silica fume content.

The effects of three different silica fume amounts on drying shrinkage were studied. When silica fumes are added to the mix, the shrinkage strains of high-strength concrete rise with time. This could be due to the expansion pastes, which produce significant shrinkage due to the increased specific surface area of silica fume. With and without fine crushed dolomite, an increase in drying shrinkage of around 5.9 and 7.2% was achieved, respectively, when silica fume increased from 0 to 15%, while an expansion in drying shrinkage of 4.2 and 5.4% was achieved when silica fume increased from (15 to 25%), as shown in Fig. 4.

4.3 Effects of Aggregate Type on Mechanical Strength and Drying Shrinkage of RPC

This study looked at the effects of two fine aggregate types (fine quartz sand with a size of up to 2 mm and fine crushed dolomite with a size of 2/5 mm) on mechanical strength and shrinkage. Fine sand with a grade of up to 600 m was employed in the most of previous RPC studies. The influence of silica fume and fine aggregate type on RPC compressive, tensile, and flexural strength at 7 and 28 days was shown in Figs. 1, 2 and 3. When compared to mixes containing only fine quartz sand with grain sizes ranging between 0.125 and 2 mm, mixtures including two types of fine aggregate demonstrated better compressive, tensile, and flexural strength. This could be due to the components of the mixture becoming more homogeneous. The aggregate grain size has little effect on the compressive, tensile, or flexural strength that can be achieved. The RPC mixtures with and without fine crush dolomite present cubic compressive strengths in the scope of 134.3 MPa and 129 MPa, tensile strengths in the scope of 11.95 and 11.53 MPa, and flexural strengths in the scope of 27.75 and 27.25 MPa, respectively, after 28 days of water curing at about 23 °C for mixes containing 25% SF. The RPC produced with local

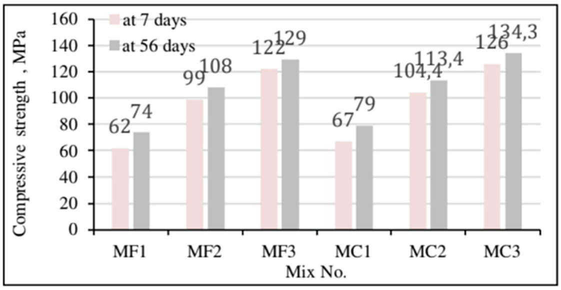

Fig. 1. Compressive strengths of RPC mixtures.

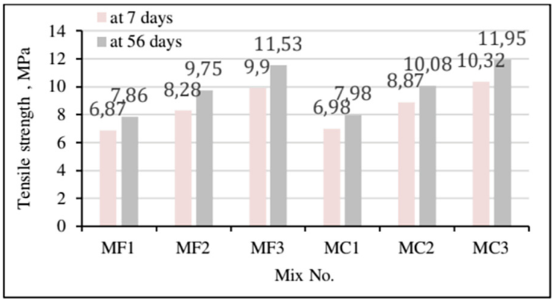

Fig. 2. Tensile strengths of RPC mixtures.

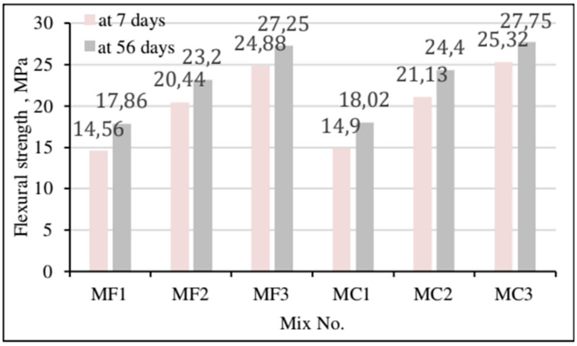

Fig. 3. Flexural strengths of RPC mixtures.

materials has strength values equal to prefabricated, commercially available goods like Ductal, according to the findings. And these results were equivalent to those obtained in [36] using coarse aggregates with a maximum grain size of 8 mm.

The findings of an experimental study of the shrinkage of RPC mixtures are presented in this study. Shrinkage refers to the loss of concrete due to physio-chemical changes that occur without the application of external stress. Shrinkage is primarily determined

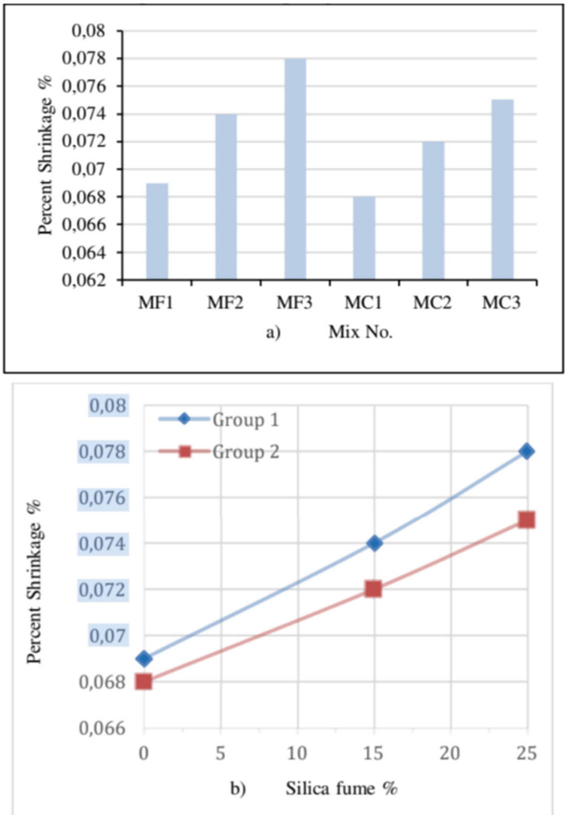

Fig. 4. a) Shrinkage percentage of the RPC mixes at the age of 60 days, b) effect of silica fume content on the shrinkage of RPC mixes.

by the paste structure, but it is also impacted by the stiffness of each component at the mixing stage [37].

The shrinkage of RPC has gotten little attention in the literature. As a result, in this study, an attempt was made to investigate the behavior of RPC using component materials that were readily available on the local market. In order to determine the length change for six mixes, (25 × 25 × 28.5) mm prisms were used. The specimens were mixed, cast, and then cured for two days in water before being exposed to the air.

For six RPC specimens, Fig. 4 depicts the length change owing to drying shrinkage. Before beginning the measurements, all specimens were cured in water for two days following demolding. As a result, at the start of the measurement, all mixes expanded in length. When the mixes were left at room temperature without being cured, they shrank. It is observed that when fine crushed dolomite is applied, shrinkage (length change) is reduced. This could be due to the fact that RPC is more homogeneous. When fine crushed dolomite was added, a decrease in change in length of roughly 1.4, 2.7, and 4% was achieved, respectively, with 0, 15, and 25% silica fume. Steel fibers help to reduce the effect of drying shrinkage while also improving compressive strength. RPC's major asset is not only its high compressive strength, but also its flexural performance. Because of fiber addition and outstanding interfacial adhesion between fibers and matrix, the RPC often gives better flexural strength and toughness. It appears that the maximum flexural strength is achieved when the silica fume level is 25% (the highest). The matrix phases are thought to begin macroscopically cracking after the first peak load. The fibers then act as a bridge between the fissures and carry the additional load.

5 Durability Properties

5.1 Water Absorption of Modified RPC

The quantity of water that enters the concrete through its voids has a significant impact on its long-term durability. For the water absorption test of RPC samples, the ASTM C642 [24] specifications have been applied. The 28 days cured specimens were first dried in a furnace for 24 h before being weighed (W_d). The dried specimens were then submerged in water for 24 h. After removing the samples from the water and drying them with a dry towel, their saturated weight was calculated, which was indicated as (W_w). The following formula is used to compute the water absorption ratio (R_a):

$$R_a = \frac{Ww - Wd}{Wd} \times 100\% \tag{1}$$

Table 3 shows the findings of an absorption test performed on various RPC mixes at 28 days of sample curing. Overall, the findings showed that the presence of steel fibers increased water absorption marginally. However, the higher the silica fume, the lower the absorption ratio. For instance, the water absorption ratio was 1.08% for MF3 of no fine crushed dolomite, 730 kg/m^3 cement content and 25% SF. However, the absorption ratio was 1.09% for its counterpart mix of fine crushed dolomite (MC3) and same amounts of cement and SF. Unlike the high performance concrete (HPC), RPC has a much lower absorption of water percentage. This is attributable to the pore size and refinement processes associated with the pozzolanic reaction, as well as the impact of superplasticizer admixture, which has a significant impact on lowering the absorption percentage, and permeability. When compared with HPC, RPC has a negligible water permeability on the 28th day [38].

5.2 Water Permeability

Permeability test was achieved according to GWT manual [25]. The variation in gauge location over a 5-min period is used to calculate the water permeability. According to the findings, the rate of water permeability at 28 days increases with the presence of fine crushed dolomite (MC3), in which, for samples of steel fibers, the minimum permeability was 0.42×10^{-4} mm/s (MC3 of 25% SF), while for its counterpart mix of no fine crushed dolomite (MF3) the recorded permeability rate was 0.41×10^{-4} mm/s. On the other hand, the use of SF has reduced the rate of permeability. This can be attributed to the filler effects of silica fume that increase the homogeneity and density of RPC mixes, resulting in low values of porosity and permeability. When compared with HPC, RPC has a negligible water permeability on the 28th day [38].

5.3 Relation Between Strength and Permeability of Designed Mixes

Results showed that the higher the compressive strength the lower the water permeability of RPC. This is due to the impact of the cement hydration that resulted in an improvement in the quantity of gel and hydration byproducts and, as a result, a reduction in RPC voids. It is well understood that the water to binder ratio gets a major impact on compressive strength and water permeability. Outside this optimum w/b ratio, increasing the w/b ratio reduces the compressive strength and increases the water permeability as a result of the high air voids contained in such mixes. On the other hand, the unworkable mix contains a high percentage of voids and will not be fully compacted, resulting in low strength and high permeability. As a result, it can be inferred that RPC mix with a fair quantity of water will achieve the highest strength and minimal permeability, assuming the concrete is completely compressed. According to the above findings, low permeability and high strength can be obtained by increasing the curing time and selecting appropriate ratios of w/b and superplasticizer.

6 Conclusions

Comparative studies on two RPC were conducted in this research. The key differences between the RPC with fine crushed dolomite and the RPC without fine crushed dolomite are the concrete proportion, mixing time, and workability. The RPC containing fine crushed dolomite is easier to fluidize and homogenize during mixing. It's likely that the mixing time will be reduced. Based on the findings, the following points can be outlined:

- Using local materials, a compressive strength of 134.3 MPa, a tensile strength of 11.95 MPa, and a flexural strength of 27.75 MPa were reached during this study. Because of the high compressive and flexural strengths attained, thinner sections and a larger range of acceptable shapes may be possible.
- The addition of fine crushed dolomite with a particle size of up to 5 mm increased the mechanical properties of RPC, and the concrete made with local fine crushed dolomite was more workable than that made with fine sand. For the RPC, as the compressive strength rises, the splitting cylinder strength and flexural strength rise as well, like in conventional concrete.
- Except for a higher modulus of elasticity and lower strains at peak stress for RPC containing fine crushed dolomite, which can be attributed to the higher stiffness of the fine crushed dolomite used, there was no discernible difference in mechanical properties under compressive stress for both RPC samples with and without fine crushed dolomite in hardened state.
- Concrete densities increase as silica fume content rises, while other contents remain constant.

RPC shrinks a lot, especially at the beginning, because of its low water-to-binder ratio and high binder concentration. High early-age shrinkage can cause early-age cracking, which can compromise serviceability, durability, and appearance. Drying shrinkage is reduced when fine crushed dolomite is used.

References

1. P. Singniao, M. Sappakittipakorn, and P. Sukontasukkul: Effect of silica fume and limestone powder on mechanical properties of ultrahigh performance concrete. Materials Science and Engineering 897 (2020).
2. P. Richard, and M. Cheyrezy.: composition of reactive powder concrete. Cement and Concrete Research 25(7), pp. 1501–1511 (1995).
3. S. Sanchayan, and S.J. Foster.: High temperature behaviour of hybrid steel-PVA fibre reinforced reactive powder concrete. Materials and Structures 49(3), pp. 769–782 (2016).
4. S. Collepardi, L. Coppola, R. Troli, and M. Collepardi: Mechanical Properties of Modified Reactive Powder Concrete. Proceedings of the Fifth Conference on Super-plasticizers and Other Chemical Admixtures in Concrete. ACI Publication SP-173, Rome, Italy, pp. 1–21 (1997).
5. J, Dugat, and N.G. Roux.: Bernier: Mechanical properties of reactive powder concretes. Materials and Structures 29(S) pp. 233–240 (1996).
6. T. Xie, C. Fang, M.M. Ali, and P. Visintin.: Characterizations of autogenous and drying shrinkage of ultra-high performance concrete (UHPC): An experimental study. Cement and Concrete Composites 91, pp. 156–173 (2018).
7. J. Liu, C. Shi, and Z. Wu.: Hardening, microstructure, and shrinkage development of UHPC: A review. Journal of Asian Concrete Federation 5(2), (2019).
8. A.Q. Ola, and H.K. Sultan.: Experimental Investigation of Effect of Steel Fiber on Concrete Construction Joints of Prism. IOP Conf. Series: Mater. Sci. Eng. 745, (2020).
9. H.H. Yahy AL-Radi, S. Dejian, and, H.K. Sultan, Performance of Fiber Self Compacting Concrete at High Temperatures. Civil Engineering Journal, 7(12), p. 2083 – 2098 (2021).
10. H.K. Sultan, A.T. Mohammed, O.D. Qasim, B.H. Maula, and H.Y. Aziz.: Ductility Factor Evaluation of Concrete Moment Frame Retrofitted by FRP Subjected to Seismic Loads. International Review of Civil Engineering (I.RE.C.E.) 11(6), pp. 275–282 (2020).
11. O.H. Zinkaah, H.K. Sultan, A. Al-Rifaie, and Z. Alridha.: Influence of Strut Geometry on the Size Effect of FRP Reinforced Simply Supported Deep Beams: A Theoretical Analysis. Mathematical Modelling of Engineering Problems 9(2), pp 411–417 (2022).
12. H.K. Sultan, and I. Alyaseri.: Effects of Elevated Temperatures on Mechanical Properties of Reactive Powder Concrete Elements. Construction and Building Materials 261, (2020).
13. ASTM C494.: Standard specification for chemical admixtures for concrete. ASTM C494. PA: ASTM, West Conshohocken. (2017).
14. Y. Ju, K. Tian, H. Liu, H.W. Reinhardt, and L. Wang.: Experimental investigation of the effect of silica fume on the thermal spalling of reactive powder concrete. Constr. Build. Mater. 155, pp. 571–583 (2017).
15. M.G. Lee, Y.C. Kan, and K.C. Chen.: A preliminary study of RPC for repair and retrofitting materials. Journal of the Chinese Institute of Engineers 29(6), pp. 1099–1103 (2006).
16. M. Cheyrezy, V. Maret, and L. Frouin.: Microstructural analysis of RPC (reactive powder concrete). Cement and concrete research. 25(7), pp 1491–1500 (1995).
17. W. Zheng, B. Luo, and Y. Wang.: Compressive and tensile properties of reactive powder concrete with steel fibres at elevated temperatures. Constr. Build. Mater. 41 pp. 844–851 (2013).
18. ASTM C1437.: Standard Test Method for Flow of Hydraulic Cement Mortar. ASTM, Philadelphia, PA. (2015).
19. ASTM C109/C109M-20b.: Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens). ASTM International: West Conshohocken, PA, USA. (2020).

20. ASTM C469.: Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. ASTM International, West Conshohocken, PA, USA. (2020).
21. British Standard Institute.: Eurocode 2: Design of Concrete Structures - Part 1. 2: General Rules - Structural Fire Design. BS EN. 1992-1-2. (2004).
22. ASTM C496.: Standard test method for splitting tensile strength of cylindrical concrete specimens. American Society for Testing and Materials Standard Practice C496, Philadelphia, Pennsylvania. (2017).
23. ASTM C293.: Standard test method for flexural strength of concrete (using simple beam with center point loading). West Conshohocken, PA: ASTM International. (2016).
24. ASTM C642.: Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. ASTM International: West Conshohocken, PA, USA (2013).
25. GWT 4000.: Instruction and maintenance manual. GWA International Limited, Germany. (2002).
26. ASTM C490–00a.: Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete. ASTM International, West Conshohocken, PA. (2000).
27. Yu R., Spiesz P., and Brouwers H.J.H..: Mix design and properties assessment of ultra-high performance fibre reinforced concrete (UHPFRC). Cement and concrete research 56, pp. 29–39 (2014).
28. Gao X.M.: Effect of Steel Fiber on the Performance of Ultra-High Performance Concrete. Doctoral dissertation, Hunan University, Changsha. (2013).
29. Bederina M., Makhloufi Z., and Bouziani T.: Effect of limestone fillers the physic-mechanical properties of limestone concrete. Physics Procedia. 21, pp. 28–34 (2011).
30. Bosiljkov V.B.: SCC mixes with poorly graded aggregate and high volume of limestone filler," Cement and Concrete Research 33(9), pp. 1279–1286 (2003).
31. Gesoğlu M., Güneyisi. E, Kocabağ M.E., Bayram V., and Mermerdaş K.: Fresh and hardened characteristics of self-compacting concrete made with combined use of marble powder, limestone filler, and fly ash. Construction and Building Materials 37, pp. 160–170, (2012).
32. Ahmad S., Zubair A., and Maslehuddin M.: Effect of key mixture parameters on flow and mechanical properties of reactive powder concrete. Construction and Building Materials 99, pp.73–81 (2015).
33. Wu Z., Shi C., He W., and Wu L.: Effects of steel fiber content and shape on mechanical properties of ultra-high performance concrete. Construction and building materials 103, pp. 8–14 (2016).
34. Alsalman A., Dang C.N., Hale and W.M.: Development of ultra-high performance concrete with locally available materials. Construction and Building Materials 133, pp. 135–145 (2017).
35. Yu R., Spiesz P., and Brouwers H.J.H.: Static properties and impact resistance of a green Ultra-High Performance Hybrid Fibre Reinforced Concrete (UHPHFRC): Experiments and modeling. Construction and Building Materials 68, pp. 158–171 (2014).
36. Kada H., Lachemi M., Petrov N., Bonneau O., and Aïtcin P.C.: Determination of the coefficient of thermal expansion of high performance concrete from initial setting. In: Materials and Structures 35(S), pp. 35–41 (2002).
37. Gupta, S.M., Aggarwal, P., and Aggarwal, Y.: Shrinkage of High Strength Concrete. Asian Journal of Civil Engineering (Building and Housing) 7(2), pp. 183–194 (2006).
38. Vivian T.W.Y.: Recycled aggregate from concrete waste for higher grade of concrete construction. Doctoral dissertation, Department of Building and Construction, City University of Hong Kong, Hong Kong. (2005).