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Investigation on Using Mineral Admixtures and Different Kinds of Aggregates onPhysical and Mechanical Properties on Reactive Powder Concrete (RPC)

Basma Adel Mohamed Abd El Rahman[1,] Al-Saaid Ibrahim Zaki El-Deen[2]
[1]PhD, Dept. of Civil Engineering,Higher Future Institute for Engineering and Technology, Dakahlia, Mansoura, Egypt.
2 Prof. in Strength of Material institute at Housing & Building Research Center (HBRC), Cairo, Egypt.

ABSTRACT
This research study the addition of mineral admixtures such as silica fume and quartz powder as partial replacement of cement using different kinds of aggregates like sand, dolomite and crushed granite in different mixes of RPC on mechanical properties such as(compressive strength, flexural strength and splitting tensile strength) and physical properties such as (absorptiontest) and compared with control mix. 35% of quartz powder and 15% of silica fume respectively were partial replaced with cement for all mixes except the control ones. Results indicated that the mix contain crushed granite aggregate has improved the compressive strength by 233.27 %, the flexural strength was improved by 121.4% and splitting tensile strength 203.61 % compared to control ones. Low absorption percentage was conducted by 2.174% in the mix containing dolomite aggregate at age of 28 days compared to control ones.

Keywords: Reactive powder concrete (RPC); Quartz powder; Crushed granite; Dolomite; Sand; Compressive strength; Flexural strength; Splitting strength; Absorption test.

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I. INTRODUCTION

During cement manufacturing a huge amount of CO_2 is produced. The reduction of cement usage would provide economic as well as ecological benefits. The greater part of cement would be replaced with proper additive the less are the costs of the concrete manufacturing.it can be seen that there are attempts to modify the composition of the concrete using various additives. These attempts are primarily designed to eliminate parts of cement mostly in 10-30% of its mass with selected additives [1].Reactive powder concrete (RPC) is an advanced type of concrete that can enhance the durability and resilience of concrete structures [2]. It was first known as reactive powder concrete (RPC) in 1990s which was developed by Richard and Cheyrezy, that introducing RPC as one of the amazing developments in the field of concrete technology [3].RPC is gaining increased interest in many countries with the usage ranging from building components, bridges, architectural features, repair and rehabilitation, vertical components such as windmills towers and utilities towers to oil and gas industry applications, off-shore structures, hydraulic structures and overlay materials. Among all these applications, road and bridge constructions are the most popular for RPC application [4]. The usage of RPC for bridges and bridge component can been seen in various countries including Australia, Austria, Canada, China, Czech Republic, France, Germany, Italy, Japan, Malaysia, Netherlands, New Zealand, Slovenia, South Korea, Switzerland and the United States (US) [5]. It consists of cement, supplementary materials (such as silica fume, fly ash, and slag cement), fine sand, quartz or glass powder, steel fiber, super plasticizer, and a low water content [2]. Coarse aggregates are excluded in many RPC mixture proportions which reduce the micro- cracks that are present in the coarse aggregate and in the interfacial transition zone between the paste matrix and coarseaggregates [6]. large amount of ordinary cement between 900-1000 kg/m^3[3] is necessary to produce RPC, with a minimum compressive strength of 150 MPa and tensile strength of 6.2 MPa. the binder accounts for almost 40% of the total mass of the mixture and silica fume accounts for 25% of the binder [7]. Silica fume accelerates the pozzolanic reactions that produce additional calcium silicate hydrate (C-S-H) and fills the voids in the paste matrix where a high compressive strength and durability are achieved [6]. Quartz powder is another filler material that account 8.4% of the total weight of the mixture. it has an average diameter slightly less than the diameter of Portland cement, which enables this material to fill voids between sand, unhydrated cement particles, and the hydration products which create denser concrete matrix resulting in increasing the compressive strength and decrease the permeability [8]. AnnaGalińskaetal. (2017),replaced from 10% to 40% of the cement mass with quartz powder and it has been proved that it affects as an increasing value of the compressive strength after 7 and 28 days and it also affects the hydration process [9].In the scientific community, the development of innovative materials and methods aiming at extending the life-time of both existing and new structures is mandatory for the sustainability of the construction sector [10]. According to Ghafari et al. (2015), the partial replacement Portland cement by incorporating supplementary cementing materials (SCMs) can be practical to produce RPC with equivalent mechanical performance [11]. In this research, 35% of quartz powder and 15% of silica fume was replaced by weight of cement mass and different kinds of aggregates such as crushed granite, dolomite and coarse sand were added to RPC respectively where mechanical such as compressive strength, flexural strength and splitting tensile strength and physical properties such as absorption test were conducted and studied for each kind of aggregate.

II. MATERIALS

In this study, ordinary Portland cement, silica fume, coarse sand, crushed granite, crushed dolomite, quartz powder, Nano-Silica, superplasticizer and ordinary tap water were used for the development of RPC mix and for the entire tests. More specifically, the raw materials used in this study were described as follows: -

2.1. Portland cement

The cement used in this study was ordinary Portland cement(CEMI 52.5 N)fromEl-Arish Portland Cement Company. Testing cement was conducted according to (ESS4756-1/2013). Tables 1 and 2 illustrate physical and chemical properties of used cement respectively.

Table 1: physical and mechanical properties of Portland cement (CEM I 52.5N).

Properties	Test results	Limits
Specific gravity	3.15	-----
Initial setting time (min.)	114 min.	Not less than 45 min.
Final setting time (min.)	240 min.	Not more than 10 hours
Fineness of cement (sieve No.170)	0.04	Not more than 10%
Expansion of cement (mm)	2mm	Not more than 10mm.
Compression strength of standard mortar	2 days (MPa)=23.3	Not less than 10 MPa
	28 days (MPa)=81.4	≥ 52.5MPa

Table 2: Chemical composition of Portland cement (CEM I 52.5N).

CEM I 52.5 N	Chemical analysis (%)	ESS 4756-1/2013
SiO_3	22.43	
Al_2O_3	4.82	
Fe_2O_3	3.44	
CaO	61.92	
MgO	1.18	
SO_3	2.45	≤ 4.0% for 52.5 N and R
L.O.I.	2.25	
Na_2O	0.43	
K_2O	0.24	
TiO_2	0.47	
P_2O_5	0.18	
Mn_2O_3	0.06	
Total	99.87	
Ins.Res.	0.49	≤ 5.0%
CI	0.08	≤ 0.10%
Na_2O Eq	0.60	
LSF	0.85	

C_3A	6.97	

2.2.Aggregates

2.2.1. Fine aggregate

Locally available natural sand as fine aggregate was used in the preparation of all test specimens according to (ECP:203-2018). Physical properties of fine sand used for the entire mixtures is shown in table 3.

Table 3: Physical properties of sand.

Properties	Test results	Limits
Specific gravity	2.5	2.5
Absorption test (%)	1.523	Not more than 2%
Final setting time (min.)	240 min.	Not more than 10 hours
Clay and fine impurities (by weight%)	2.5	Not more than 3 %
Fineness modulus	2.6	-------

2.2.2. Coarse aggregate

Locally available crushed granite and dolomite were usedas coarse aggregate according to (ECP: 203-2018) in this research study. Tables 4 ,5 and 6 show the chemical composition of crushed granite, dolomite and physical properties of each one respectively.

Table (4): Chemical composition of crushed granite.

Crushed granite	Chemical analysis (%)
Carbon (C)	------------
Oxygen (O)	58.01
Sodium (Na)	0.89
Magnesium (Mg)	1.26
Aluminum (Al)	6.91
Silicon (Si)	17.76
Potassium (K)	3.01
Calcium (Ca)	0.92
Titanium (Ti)	0.96
Iron (Fe)	10.28

Table (5): Chemical composition of dolomite.

Dolomite	Chemical analysis (%)
SiO_3	0.49
Al_2O_3	0.1
Fe_2O_3	0.1
CaO	31.78
MgO	20.85
MnO	-----------
Na_2O	0.1
K_2O	0.1
SO_3^{-2}	-------------
S^{-2}	-------------

Table (6): Physical properties of dolomite and crushed granite.

Properties	Test results	Limits
For dolomite:		
Specific gravity	2.7	2.6-2.7
Absorption test (%)	1.39	Not more than 2.5 %

Clay and fine impurities Maximum nominal size (mm)	2.5 9.5mm	Not more than 3% --------
For crushed granite: Specific gravity Maximum nominal size (mm)	 2.7 9.5 mm	 2.6-2.8 ----------

2.3. Admixtures
2.3.1. Mineral admixtures
Locally available mineral admixtures such as silica fume and quartz were used in this research work as a replacement of cement. The percentage used in silica fume was 15% by weight of cement while for quartz was 35% by weight of cement used [12]. Tables 7 and 8 illustrate the physical and chemical properties for both silica fume and quartz respectively.

Table 7: Physical and chemical properties of silica fume.

Silica fume	Chemical analysis (%)
SiO_2	96
FeO_3	1.45
Al_2O_3	1.10
CaO	1.20
MgO	0.18
K_2O	1.20
Na_2O	0.45
SO_3	0.25
H_2O	0.85
Physical Properties	
Color	Grey
Specific gravity	2.15
Density	345
Particle volume	7000

Table 8: Physical and chemical properties of quartz.

Silica fume	Chemical analysis (%)
SiO_2	99
$MgCO_3$	0.01
Fe_2O_3	0.03
CaO	0.03
Al_2O_3	0.05
SO_3	3.03
Physical Properties	
Color	Grey
Specific gravity	2.65

2.3.2. Chemical admixtures
Commercially available super plasticizer of type G according to ASTMC494 supplied by SIKA Company Limited in Egypt under the commercial name Sika Viscocretewas used in this study to attain workability of concrete mixes.

2.4. Water
Ordinary drinking water was also used for preparation of the desired concrete mixesand curing.

III. EXPRIMENTAL WORK
3.1. Proposed mix design for reactive powder concrete
In general, cement was partially replaced by combination of silica fume and quartz powder with different percentages. It was designed using silica fume at 15% by weight and quartz powder at 35% by weight. The control mix were developed from Portland cement, superplasticizer, fine sand, water

and dolomite. For all mixes, mechanical mixing, standard water curing and uniform water-binder ratio of 0.2 were used. As shown in table 9, four Mixes were utilized including the control mix.

Table 9: Mix design for 1 m^3RPC under this study.

Mix no_	Mix description	Mix Proportions for 1 M^3 of Concrete							
		CEM Kg/m^3	Sand Kg/m^3	Dolomite Kg/m^3	Crushed granite Kg/m^3	Silica fume Kg/m^3	Quartz powder Kg/m^3	S.P. Kg/m^3	Water Kg/m^3
M1	15%S.F.+35%QP + dolomite	1000	153.8	546	---------	150	350	200	20
M2	15% S.F.+35% QP + crushed granite	1000	153.8	------	546	150	350	200	20
M3	15%S.F.+35%QP + sand only	1000	658.2	-----------	-----------	150	350	200	20

3.2.Specimen preparation and curing procedure

Concrete specimens were prepared based on (ECP 4756-1/2013)by preparing watertight and non-absorbent 100 × 100 × 100 mm^3 cube, 150 × 300 mm^3 cylinder and 100 × 100 × 500 mm^3 prism molds.

In order to prepare specimens, dry mixing of ingredients was done for 1 min. After that, wet mixing was done by adding the water and all of superplasticizer into the mixed dry materials and was mixed for another 1 min. untila visually acceptable mix was obtained. Mechanical mixing was employed throughout the entire specimen preparations. After getting a uniform mix and placing layer by layer on molds, compaction was employed in three layers by steel compacting rod of circular cross-section having 16 mm diameter and length 600 mm with rounded ends. Once leveling of the surface was made with steel floats, the specimens were left in the molds for one-day till getting dry. After removal of specimens from the mold, the specimens were marked without damaging them. Then, standard curing of the test specimens was done till testing days for 2, 7 and 28 days in water at a temperature of 20 ± 2°C.

3.3. Testing program

For testing, before placing the test specimens centrally in the testing machine, any excess moisture from the surface of the specimen were wiped. Then, three specimens were tested for the mechanical properties of RPC as per the Egyptian Standard testing procedure for hardened concrete (ESS4756-1/2013) in High Institute for Engineering and Technology(College)- Concrete and Materials laboratory.

The compressive strength was tested by automatically controlled testing machine at constant rate of loading at the age of 2, 7 and 28 days and the tensile splitting strength at age of 28 days where standard water curing took place and the average values were reported. In addition to this, the flexural strength was determined at age of 28 days of standard water curing. For testing the flexural strength, two supporting steel rollers and one upper roller was used for applying loads in the universal testing machine at a constant load rate.

Beyond the mechanical performance, absorption test of the developed specimens concrete of all mixes were conducted in this study. For this purpose, samples were taken from each mix and dried for 24 hours in the oven at a temperature of 105±5°C after 28 days standard curing then the samples were weighted after drying after that the samples were immersed in the water for another 24 hours and weighted again then the absorption percentage for each mix was calculated according to (ESS4756-1/2013).

IV. RESULT AND DISCUSSION

4.1. The **effect of silica fume,quartz powder and different kinds of aggregates on mechanical properties of RPC concrete.**

Concrete is one of the most common and widely used construction materials in which its properties have been well studied at macro or structural level without fully understanding the properties of the cementitious materials at the micro level. The rapid development of the characterization techniques makes it possible to characterize cementitious materials at micro-scale level. The betterunderstanding of the structure and behavior of concrete at micro-scale could help to improve concrete properties and make concrete more durable [13]. Characteristics like, durability, impermeability and volume stability may be important in some case of designing concrete structure but strength is the most important one since an overall picture of concrete quality is being reflected by the concrete strength [14].

In this study, after partial replacement of cement by silica fume and quartz powder at 15% and 35% percentages respectively using different aggregates and testing at the respected ages, its properties were identified and investigated. The mechanical performances of the reactive powder concrete in this study were evaluated by compressive strength, split tensile and flexural strength. Table 10 shows the mechanical properties of RPC containing silica fume,quartz powder and different kinds of aggregates.

Table 10. Mechanical properties of RPC containing S.F., Q.P. and different kinds of aggregates.

Mix no_	Mix designation	2 days (MPa)	7 days (MPa)	28 days (MPa)		
		Compressive strength	Compressive strength	Compressive strength	Flexure strength	Splitting tensile strength
1	15%S.F.+35%Q + dolomite	38.55	67.95	139.79	12.00	15.00
2	15% S.F.+35% Q + crushed granite	57.17	76.94	183.3	21.00	16.00
3	15%S.F.+35%Q + sand only	37.76	57.95	72.67	17.34	14.15

4.1.1. Compressive Strength

Compressive strength in this study was evaluated by replacing different percentages of the proposed materials. The mean compressive strengths of three UHPC specimensincluding control mixwere presented in Figure 1.

As shown in Figure 1, the compressive strength increases with the curing age in all mix. In early age at 2 days standard curing, 57.17 MPa were observed as a maximum mean value using in mix 2 containing 15% silica fume (S.F.) and 35% quartz powder (Q.P.) and crushed granite as coarse aggregate. In7 days standard curing, 76.94 MPa maximum strength were observed in the same mix 2. Similarly, in 28 days standard curing, mix 2 gives a maximum mean compressive strength of 183.3 MPa compared to control mix by increasing improvement of 233.27%.

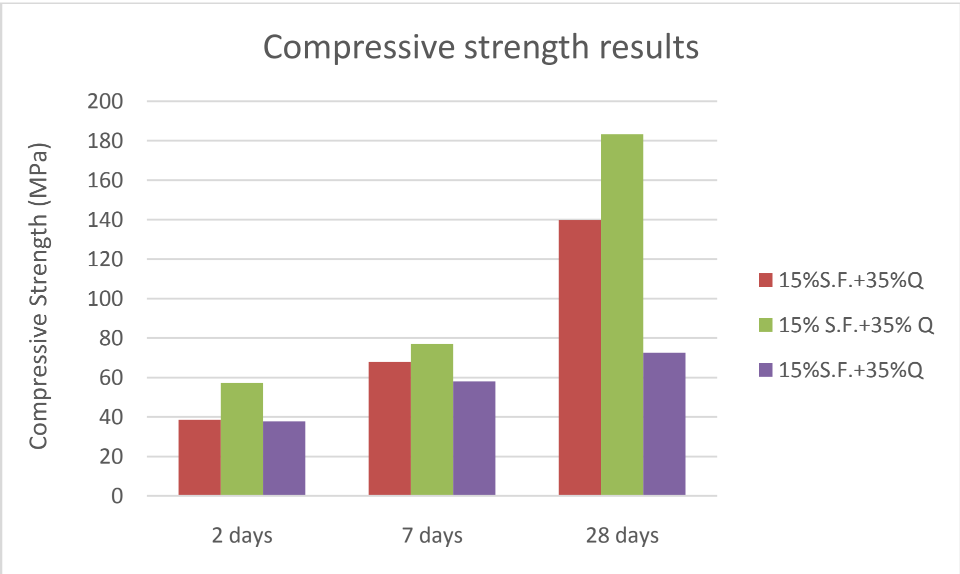

Fig.1: Compressive strength results of four mixes at different ages of curing.

4.1.2. Split Tensile Strength

On the other hand, the effects of silica fume, quartz powder and different kinds of aggregates on split tensile strength of RPC were evaluated in this study. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack.

Figure 2 shows the split tensile strength of RPC produced in this study. As it was observed in Figure 2, the maximum split tensile strength were in Mix 2 containing15% silica fume (S.F.), 35% quartz powder (Q.P.) and crushed granite as coarse aggregate combinations. Compared to the control mix,203.6% greater strength were achieved at 28 days standard curing.

4.1.3. Flexural Strength

The other mechanical strength evaluation for the developed RPC in this study was performance evaluation by flexural strength of beams. According to dictionary of construction, flexural strengthis defined as a property of a material or structural member that indicates its ability to resist failure in bending. Figure 3 shows the flexural strength of RPC containing 15% silica fume, 35% quartz powder and different kinds of aggregates including the control mix. Accordingly, a maximum flexural strength 21 MPa was observed using Mix 2. Compared to the control mix, 121.4% was improved using the series

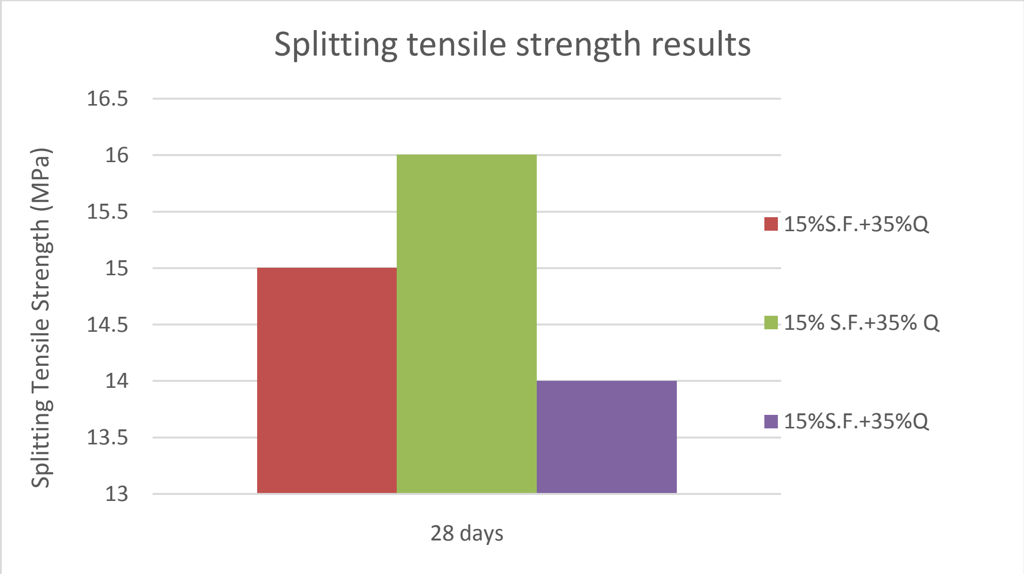

Fig.2: Splitting tensile strength results of four mixesat age 28 days of curing.

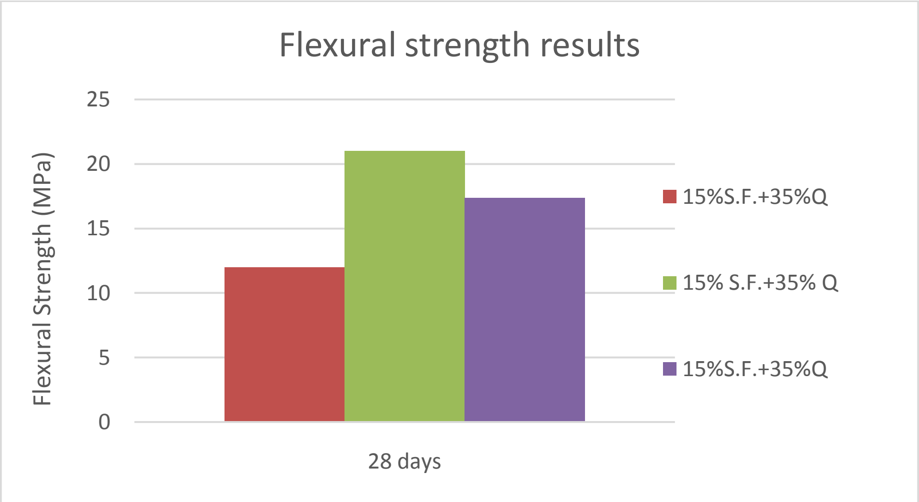

Fig.2: Flexural strength results of four mixes at age 28 days of curing.

Accordingly, in this study the combined effect was evaluated for partial replacement of silica fume and quartz and using different kinds of aggregates in RPC development. The experimental results indicated that a mean compressive strength of 183.3MPa, flexural strength of 21 MPa as well as 16 MPa split tensile strength were developed using 15% silica fume (S.F.) and 35% quartz powder (Q.P.) and crushed granite as coarse aggregate at 28 days standard curing.

4.2. The effect of silica fume, quartz powder and different kinds of aggregates on physicalproperties of RPC concrete.

4.2.1. Absorption test

Table 11 and figure 4 illustrate the absorption results of alternative specimens of RPC including control ones at age of 28 days of curing.It is shown that minimum absorption result (%) was developed using 15% silica fume (S.F.) and 35% quartz powder (Q.P.) and dolomite as coarse aggregate at 28 days standard curing. 2.174 % was conducted compared to control ones.

Table 11. Absorptionresults of RPC containing S.F. and Q.P. and different kinds of aggregates.

Mix no_	Mix designation	Absorption results (%) at age 28 days
1	15%S.F.+35%QP + dolomite	2.174
2	15% S.F.+35% QP + crushed granite	4.440
3	15%S.F.+35%QP + sand only	2.270

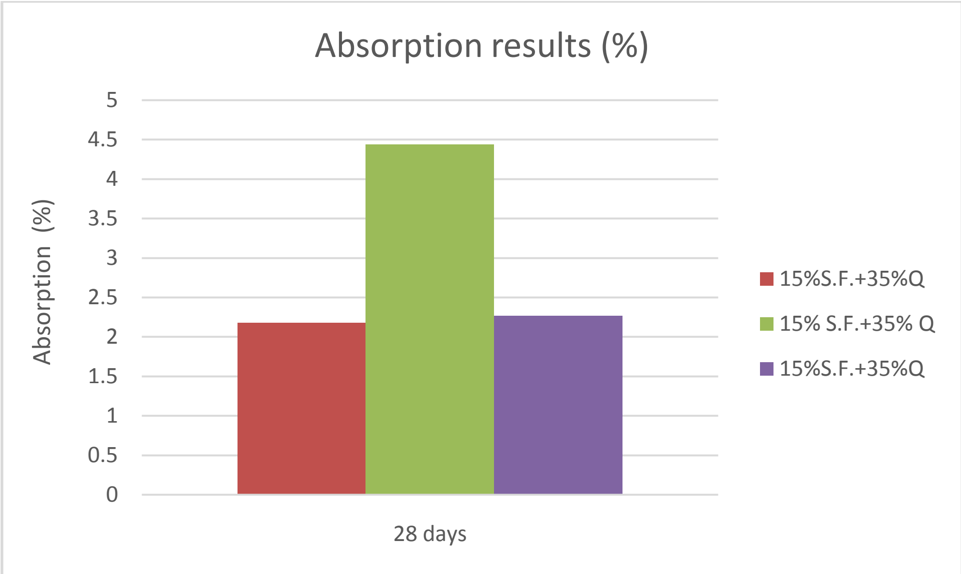

Fig.3: Absorption results (%) of four mixesat age28 days of curing.

V. CONCLUSIONS

This study was conducted to evaluate the mechanical and physical properties of RPC containing silica fume and quartz powderas partial replacement of cement as well as different kinds of aggregates. Standard curing was adopted for this study. Accordingly, the following conclusions can be drawn:

- In allRPC mix designs, good pozzolanic effect and good density were observed.
- The mechanical properties of RPC were increased with the curing age. Accordingly, for partial replacements of cement by silica fume and quartz powder using different kinds of aggregates,183.3 MPa compressive strength, 16 MPa tensile splitting strength and 21 MPa flexural strength were observed after 28 days standard curing for mix containing 15% silica fume (S.F.) and 35% quartz powder (Q.P.) and crushed granite as coarse aggregate.
- Good absorption percentage was observed from the absorption analysis. Hence, for partial replacements of cement by silica fume and quartz powder using different kinds of aggregates, 2.174% was achieved for the mix containing 15% silica fume (S.F.) and 35% quartz powder (Q.P.) and dolomite as coarse aggregate at 28 days standard curing.

Declarations

Availabilityofdataandmaterials

Notapplicable.

Competinginterests

Not Applicable.

Funding

Not applicable.

Authors'contributions

Not applicable.

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Authors'information

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