NEW GENERATION OF REACTIVE POWDER CONCRETET WITHOUT EXTERNAL CURING

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Abstract - Due to the development of using Reactive Powder Concrete (RPC) in many application and because the difficult of special curing to RPC in site so there's a serious demand to find new ways for curing that's reason beyond concept of the present investigation. In this study, the effect of Self-Curing Agent (Polyvinyl Alcohol) on the mechanical propertiesas an addition varying percentage of (Polyvinyl alcohol (PVA) by weight of cementitious material from 0.5% to 1.25% were studied for reactive powder concrete mix., Reactive powder concrete (RPC) specimens were designed, prepared and cured for different ages (7, 28 and 60) days. The specimens prepared to study compressive strength, splitting tensile strengthand flexural strength with Self-Curing Agent (PVA) as an addition .It was found thatthe compressive strength of concrete with the special curing (PVA)higher than the referenceconcrete, and also the same trend was observed for the splitting tensile strength. The improvement in the compressive strength at 28 days when using (PVA) with 0.75% percent by weight of cementitiuos material as internal curing has been about (43.77%).while the improvement in the splitting tensile strength was (11.59%). Flexural strength was also affected by internal curing, theflexural strength were (18.87MPa) for reference became (23.58MPa) when curing with PVA .

Keyword - Self-curing concrete; Reactive Powder Concrete; Polyvinyl Alcohol Silica fume; mechanical properties; Dry-air curing.

I. INTRODUCTION

Reactive powder concrete (RPC) is one of the latest and most important development in concrete technology , it has received great attention in recent years in the world due to its superior mechanical properties such as; high strength, high ductility, high durability, limited shrinkage, high resistance to corrosion and abrasion (1).

The very dense structure of high-performance concrete might lead to the assumption that water evaporation is low and therefore water from the surrounding can penetrate only very slowly and not in a sufficient amount to reach the interior of the member. So, the effect of curing can therefore be neglected. Saving the curing time would positively influence the construction costs. On the other hand when exposed to air, water evaporation was observed resulting in a considerable reduction of the compressive strength and micro cracks appear (2,3). Many researches (4) showed failure of the traditional curing methods for HSC. Wet curing for a longer time even submersing in water did not always positively influence the mechanical properties. Hence, the opinions in the literature about curing high strength concrete are contradictory. Self-curing or internal curing is a technique that can be used to provide additional moisture in concrete for more effective hydration of cement and reduced self-desiccation.

Particularly in high performance concrete (HPC), it becomes increasingly difficult to provide curing water from the top surface that is adequate to satisfy the ongoing chemical shrinkage. At this time, the cement paste is searching for water. Without adequate water, stresses develop that can lead to chemical shrinking, autogenously shrinkage, early age cracking and micro-cracking. Internal curing caneliminate or largely reduce these detrimental conditions, improving the quality, life expectancy, and sustainability of the concrete (5).

Using PVA in concrete enhanced the physical properties of concrete as proved in recent researches studied the effect WC ratio Polyvinyl alcohol-to-Cement (P/C) ratio on flexural ity of cement paste The maximum increase in flexural strength occurred when W / C ratio is 30 % and P/C ratio is 0 016 % (6).

The usage of PVA gives higher compressive strength and spilt tensile strength compared to the normally used water cured specimens without self-curing chemicals. It is observed that the specimen with PVA when placed outside the lab gives same result as that of normal water cured specimen , Thus it is found that addition of PVA in high dose over 1.5% of cement would not give expected results in strength and those cannot be used practically(7).

II. RESEARCH SIGNIFICANCE

The principal aim of this paper is to evaluate the effects of differentpercentage of self-curing agents on themechanical properties of concrete (such as compressive, tensile,flexural strength and modulus of elasticity). The self-curingagents employed in this paper were chemical agent of poly-vinyl alcohol (PVA)with different ratios (0.5, 0.75, 1 , 1.25) and cured in dry air (25 _C) during the experiment. The results should help explain the effect of self-curing agents on the mechanical properties of concrete. Also, the results provide more knowledge about the determination of self-curing agent ratios and the best

ratio to optimize the mechanical properties of concrete.

III. CONSTRUCTION MATERIALS

Cement

Ordinary Portland cement (type I) manufactured in Iraq brand of (KARASTA) was use in this research. It was stored in a suitable way to avoid any exposure to hazard conditions. The chemical properties of cement used throughout this research are shown in Table (1). Test results were indicated that the adopted cement was conformed to the Iraqi specification No.5/1984.

Compound Composition	Chemical Composition	Percentage By Weight	Limits of Iraqi Specification No.5/1984
Lime	CaO	61.9	----
Silica	SiO_2	18.8	----
Alumina	Al_2O_3	4.8	----
Iron Oxide	Fe_2O_3	2.7	----
Magnesia	MgO	2.5	5.0% (max)
Sulfate	SO_3	2.6	2.80% (max)
Loss on ignition	L.O.I.	4.5	more than 4.0 (EN 197-12)
Insoluble residue	I.R.	0.21	1.5(max)
Lime saturation factor	L.S.F.	0.94	(0.66-1.02)%

Table (1):-Chemical composition of cement.

Natural Sand

Al-Ekhaider natural sand was used throughout this research as the fine aggregate with particle size distribution smaller than 600 μm and greater than 150 μm.

Micro Silica Fume (SF)

Silica fume is a by-product of the manufacture of Silicon metals from Ferro silicon alloys in the electric arc furnace. Densified micro silica from (FINNFJORD) Company localized in Norway was used throughout this research. Table (2) illustrated its chemical analysis and physical properties respectively of the used micro silica fume and compared with the requirements of (ASTM C1240, 2015).

composition	Oxide content %	ASTM C-1240 Limitations
SiO_2	89.4	≥ 85
Al_2O_3	0.33	- - -
Fe_2O_3	1.28	- - -
CaO	0.95	< 1
MgO	2.47	- - -
K_2O	0.07	- - -
Na_2O	0.06	- - -
SO3	1.19	< 2
L.O.I.	3.4	≤ 6.0
Blaine fineness	(m2/kg) 200000	

Table (2):- Composition and Properties of Silica Fume.

Micro Steel Fibers

The micro steel fibers employed in this investigation are 13 mm length and 0.2 mm diameter, clean of rust or oil. This type of micro steel fibers was manufactured by the (Ganzhou Daye Metallic Fibers Co., Ltd, China).The steel fibers were imported in 25 Kg bags, sample of steel fibers before and after magnification with macro lens (25-58) mm. Straight and brass-coated micro steel fibers were used and the properties of the used steel fibers are presented in Tables (3).

Property	Specifications
Surface	Brass coated
Relative Density	7825 Kg/m3
Tensile Strength	Minimum 2400MPa
Form	Straight
Melting Point	1500°C
Average Length	13±1 mm
Diameter	0.2mm±0.05mm
Aspect Ratio (Lf/Df)	65
Type	WSF021

Table (3):- Technical description of the used superplasticizer.

Self-Curing Agent (Polyvinyl Alcohol)

Commercially Polyvinyl alcohol is produced from polyvinyl acetate by a continuous process. The acetate groups are hydrolysed by ester interchange with methanol in the presence of anhydrous sodium methyl ate or aqueous sodium hydroxide. Polyvinyl alcohol is an odourless and tasteless, translucent, white or cream coloured granular powder. It helps to retain water in concrete. It is soluble in water, slightly soluble in ethanol, but in soluble in other Organic solvents. Typically a 5% solution of polyvinyl alcohol exhibits a PH in the range of 5.0 to 6.5 polyvinyl alcohol has a melting point of 1800 to 190oC. Polyvinyl alcohol is a water soluble synthetic polymer. Polyvinyl alcohol has excellent emulsifying

and adhesive properties as shown in table(4) and, PVA is fully degradable and dissolves quickly.

Properties	Value
Melting point (Tm)	220 oC
Tg	75 – 85 oC
PH	5 – 7
Molecular weight (MW)	26,300 – 30,000
Degree of hydrolysis	86.5 – 89 %
Bulk density	0.68 g/cm3
Hardness	83.3 (shore D)
Decomposition point	240 ◦C

Table (4):- properties of polyvinyl alcohol.

High Range Water Reducing Admixture (HRWRA)
The high range water reducing admixture used in this research is a third generation super plasticizer for concrete and mortar, which is known commercially as (Hyperplast PC200), It is a High-Performance Super plasticizer Concrete Admixture which is imported from (DCP) company, it is aqueous solution of modified polycarboxylic polymers with long chains, free from chlorides and complies with (ASTM C494 / C494M, 2017) .

Mixing water
Water used for all the mixes was normal tap water from the domestic water supply. In general, the mixing water of the concrete lab was fresh and free of acids, organic matter, suspended solids, alkalis and impurities which when presented may have adverse effect on the properties of concrete. The temperature of the mixing water was maintained at (25±2) □.

Mix Proportions
Three RPC trials mixes with steel fiber for internal curing were used in this research in order to achieve the maximum compressive strength and flow according to (ASTM C109, 2016 and ASTM C1437, 2015) respectively. Trials mixes for internal curing were used in this study as presented in Table (5) to evaluate the performance of the RPC mixes in their fresh and hardened state.
A number of mixing proportions from the previous literature were taken into consideration and playing around with these mix proportions, numerous mix proportions were established.
In this kind of concrete, homogeneity is improved by using a powder concrete in which aggregates and traditional sand are replaced by ground quartz less than 600 microns in size. The high cement content of ordinary Portland cement, with a different amount, is used to achieve greater strength.
The following type of material that used in the preparation of the Fife RPC trials mixes:

1. Type of cement, one local manufactured cement types were KARASTA.
2. Type of silica fume, one type of imported silica fume were used.
3. One types of super-plasticizers were used PC 200.

After that was chosen the mix that gave maximum compressive strength at 28 days.

mixture	Cement Kg/m3	Sand Kg/m^3	Silica Fume %	Silica Fume Kg/m^3	w/ cm ratio	S.P by wt. of cm (%)	Micro Steel Fiber *Vf %*	Micro Steel Fiber Kg/m3	Compressive Strength at 28 Days (MPa)
S1	960	1020	24	235	0.16	7	2	157	128.4
S2	960	1030	25	240	0.17	7.5	2	157	125.3
S3	980	1050	25	245	0.16	7.5	2	157	130.9

Table (5):- RPC trial mixes of internal curing.

Mixing Procedure
All trial mixes were performed in a small rotary mixer of (0.01m3) capacity, while the specimens' mixes were performed in a horizontal rotary mixer with a capacity of 0.09 m3 . Any residual particles of concrete from prior batch must be cleaned off before using the concrete mixer. A moist cloth is used to clean the blades and pan of the concrete mixer.
For reference reactive powder concrete:-

1) The micro silica fume powder was mixed in dry state with the required quantity of fine sand for 5 minutes.
2) Cement was loaded into the mixer with dry mixing of the components for about 4 minutes to break the agglomerates.
3) Addition of water containing of superplasticizers progressively during mixing for about 3 minutes.
4) When the flowable consistency achieved the steel fiber or carbon fiber added gradually during the operation of the mixer to insure the uniformly dispersion which takes about 4 minutes.
5) The whole time of mixing process takes about 15 minutes.

The methods of mixing have been made and tested the samples to obtain a higher strength with the best mixture and flow with PVA. Polyvinyl alcohol has a melting point of 180 to 190°C. Therefor PVA mixing with water of mixing and heating for a melting point than add to mixture.
With each mix, samples were prepared to determine the mechanical properties of concrete involve 3 cubes (50×50×50 mm) for compressive strength, 3 cylinders (100×200 mm) for splitting tensile strength, 3 cylinders (100×200 mm) for modulus of elasticity and 3 prisms (50×50×300 mm) for flexural strength.

Specimen's Preparation And Casting Procdure
Specimen's molds were cleaned thoroughly, tightened well and the internal surfaces were oiled with thin car engine oil to prevent the adhesion of

hardened Concrete with molds.Once the concrete mixing was done, the molds were filled with RPC. A vibrating table was used for consolidation of RPC molds. After being molded, all the specimens were cured under polyethylene sheets for about 24hr in the laboratory environment.

Curing

The specimens were divided into two groups according to their curing .The 1st group used Conventional Curing as water . The 2nd group that curing with Self-Curing Agent (Polyvinyl Alcohol).For the specimens that kept in ambient "environments inside the "laboratory without any curing that considered as a reference or control for comparing

After casting another group of RPC specimens contain PVA after demolded there were kept in ambient "environments inside the "laboratory with a temperature of (20±2 °C) until "the age of test.

Compressive Strength

Compressive strength is the most important property of concrete since the first consideration in structural design is that the structural elements must be capable of carrying the imposed loads. It is used toestimate the potential strength of concrete. The characteristic of concrete compressive strength is used to classify the concrete in the national and international codes .The test of compressive strength (fcu) was carried out using (50×50×50) mm cubes for RPC; these cubes were cast using RPC with 2% micro steel fiber were tested at ages of 7, 28 and 60 days. The results were compared with RPC cubes tested at laboratory without any curing at the same ages.

Mixtures	PVA % by eight of binde	Compressive Strength(Mpa)		
		7 Days	28 Days	60 Days
M1	DRPC	66	76.63	78.82
M2	WRPC	108.9	130.9	136.22
M3	$PVRPC_{0.5\%}$	90.2	99.3	105.13
M4	$PRRPC_{0.75\%}$	87	110.17	121.17
M5	$PVRPC_{1\%}$	78.2	99.4	108.76
M6	$PRRPC_{1.25\%}$	81.6	105.6	113.32

Table (6):- Results of Compressive Strength (Mpa)

In the present study, the effect of admixture PVA on compressive strength test by addition varying percentage of Poly viynal alcohol (PVA) by weight of cementitious material from 0.5% to 1.25% were studied for reactive powder concrete mix. It is clear from the results the compressive strength improve with increasing the dosage of PVA for all ages are shown in Table (6) and plotted in Figure (1).It was also found that 0.75% of PVA by weight of cementitious material was optimum for this mix of RPC concretes for achieving maximum. The first group RPC specimens were kept until 28 days in tap water with a temperature of (23±2 °C) as illustrate in plate (4)and after that "kept in ambient "environments inside the "laboratory until "the age of test. The second best curing for reactive powder concrete after water curing was by addition polyvinyl alcohol (PVA) by weight of cementitious material. Obviously that the development of strength became more rapid from 7 days to 60 days due to the self-curing main concept is to reduce the evaporation of water from concrete and therefore increase the water retention capacity of the self-cured concrete when compared to conventional concrete by using chemical curing agents. The compressive strength increased may be ascribed to the better relation between the cementitious material and the water content leading to produce much quantities of hydrates. The development in compressive strength of the concrete can be mostly attributed to the more consumption of Ca(OH)2, better pore refinement, micro filling action, early gain of strength, and higher pozzolanic reaction.

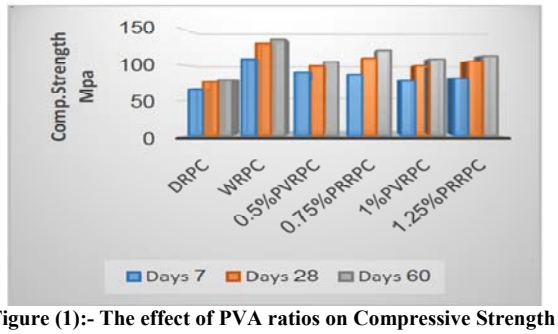


Figure (1):- The effect of PVA ratios on Compressive Strength development with age.

Splitting Tensile Strength

Splitting tensile strength was performed by using a cylinder with dimensions (100×200) mm at ages (7, 28 and 60 days). By applying the same procedure used in the calculation of compressive strength, each test was conducted by three cylinders. Concrete specimens with different curing regime such as a water curing, and (PVA) have been study their effect on the behavior of concrete under splitting tensile stresses and compared with the reference mix that didn't use any type of curing. The values of splitting tensile strength considered in the present investigation are summarized in Table (7).

Mixtures	PVA % by weight of binder	Splitting Tensile Strength (Mpa)		
		7 Days	28 Days	60 Days
M1	DRPC	9.11	10.87	11.81
M2	WRPC	12.5	15.44	15.91
M3	$PVRPC_{0.5\%}$	9.54	11.59	12.27
M4	$PRRPC_{0.75\%}$	9.85	12.66	13.34
M5	$PVRPC_{1\%}$	10.12	12.57	13.17
M6	$PRRPC_{1.25\%}$	9.67	12.13	13.01

Table (7):- Results of Splitting Tensile Strength (Mpa) with age.

The tensile strength governs the cracking behavior and it affects other properties such as stiffness and durability of RPC.

However, the tensile strength of concrete is much less, than the compressive strength and this attributed to the ease propagation of cracks under tensile loads (8). Increasing of strength with time is the result of the progress of the hydration process of the matrix through the completion of its inner microstructure leading to additional strength added to the composite material, along with the increase in the bond strength between the fibers and the matrix (8). As in compressive strength.

The results of PVRPC that shown in Table (8) and plotted in figure (2) indicated that the development that occurs at the early ages 7 days is slow as a result of the water retention in concrete at the few days after casting, but after that duration RPC start the necessity to water for the purpose of completing the process of hydration. Therefor it is also noted that the rate of tensile strength development of the PVRPC is increasing at the 28and 60 days respectively.

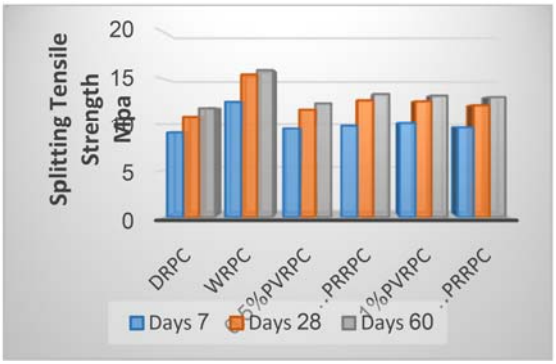


Figure (2):- Splitting Tensile Strength (Mpa) with age.

Flexural Tensile Strength

Each prism was tested as simply supported and subjected to two-point loading. Below Table presents the tested results in which each value in this table represents the average value of (3) prismatic samples in order to minimize the expected error in any measured result.The flexural strength of the specimens is shown in table (8). There are considerable increases in the flexural strength due to effects of the steel fibers and RPC self-curing that use in this study.

It can be concluded that the rate of flexural strength gain of the WRPC, PV-RPC at the first month is higher than those at the later ages as shown in figure (3). This behavior may be attributed to the better crystallization of the hydrates and activation of pozzolanic reaction due to available of water retention in concrete body within thefirst month. WRPC (water curing) shows the higher increment in in the flexural strength while PVA percentage gives excellent curing compare with reference mix DRPC. This increment may be related to the ability of these mixtures to produce more hydrates and less capillary pores, thereby strengthen the microstructure and reducing the micro-cracking.

Mixtures	PVA % by weight of binder	Flexural Tensile Strength (Mpa)		
		7 Days	28 Days	60 Days
M1	DRPC	15.44	18.87	19.54
M2	WRPC	17.65	26.49	27.54
M3	$PVRPC_{0.5\%}$	15.78	20.96	22.05
M4	$PRRPC_{0.75\%}$	16.55	23.58	24.63
M5	$PVRPC_{1\%}$	16.21	21.88	23.67
M6	$PRRPC_{1.25\%}$	15.97	21.52	23.28

Table (8):- Results of Flexural Tensile Strength (Mpa)

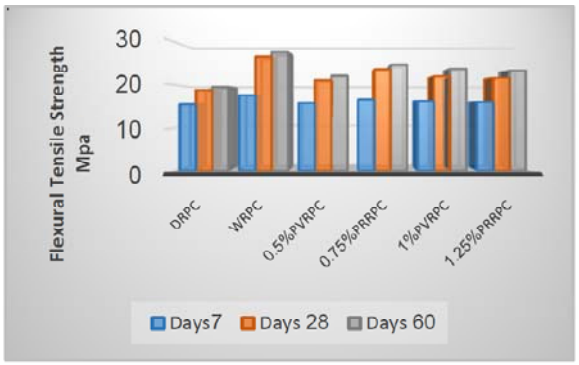


Figure (3):- Flexural Tensile Strength (Mpa) with age.

IV. CONCLUSIONS

In this research, a series of experiments have been performed toinvestigate the behavior and the properties of self-curing reactive powder concrete. Based on the experimental results presented in this paper, the following conclusions could be drawn as follow:

1. The main properties of Reactive powder concrete depend on the type of curing.
2. The use of self-curing agents (Polyvinyl Alcohol) in RPC mixes improves the mechanical properties of concretes under air curing regime which may be attributed to a better water retention and causes continuation of the hydration process of cement paste resulting in less voids and pores, and greater bond force between the cementpaste and aggregate.
3. The optimum dosage of self-curing admixture PVA is found to be 0.75% by weight of cementatious material for reactive powder concrete for compressive strength spilt tensile strength and flexural strength. Higher cement content and lower water/cement ratio leads to more efficient performance of self-curing in concrete.
4. The maximum Percent of increase in Compressive Strength when use PVA was about 53.80% while 12.95 % inSplitting Tensile Strength and in Flexural Tensile Strength 20.05 % at 60 days.
5. That addition of PVA in high dose over 1.25% of cementatious material would not give expected results in strength due to the difficult of compacting with compromising workability.

6. Auto cleave curing or hot water curing of reactive powder concrete is less capable than Self-Curing it can be applied to simple as well as complex shapes.

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