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Effect of Elevated Temperature on the Compressive Strength of Reactive Powder Concrete (RPC) Containing Polyvinyl Chloride (PVC)

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Abstract: ***Fire is the most sever environmental condition affecting on concrete structures, thus investigating for fire safety in structural concrete is important for building construction. The slow heat transfer and strength loss enables concrete to be effective for fire resistance. Concrete structures withstand when exposed to fire according to: their thermal properties, rate of heating, characteristic properties of concrete mixes and their composition and on the duration of fire, and concerned as thermal property with other factors such as loss of mass which affected by aggregate type, moisture content, and composition of concrete mix. The present research goal is to study the effect of rising temperature on the compressive strength of the reactive powder concrete samples. Then investigate the behavior of reactive powder concrete when using poly vinyl chloride PVC and exposed to elevated temperature from zero to 600C^o.***

Keywords: effect of elevated temperature on concrete, polyvinyl in concrete, reactive powder concrete.

1. Introduction

(RPC) Reactive Powder Concrete is a new inventory of high compressive strength(up to 200 MPa), its composite materials may enhance its workability to possess excellent static and dynamic strengths, good durability under severe conditions and high fracture capacity, and low shrinkage .The microstructure of RPC is organized by gradation of the particles in the mix to achieve maximum compactness. RPC improves tensile strength, before and after cracking which is resulted from the interaction of the fibers of steel that is randomly oriented, working as a micro reinforcement and prevents the formation of cracks due to steel fibers effect where they are able to sustain additional tensile loads till fibers pulled out from the matrix [1].The granular(silica fume, quartz powder, sand and cement) optimization is important for enhancing durability and mechanical properties. [2].

Results indicated that high strengths RPC mixes could be suitable for structures of nuclear waste containment [3].

2. Behavior of Concrete under High Temperature

The most important effects of high temperature on concrete are: cement pastedehydration, increase in porosity, thermal expansion and creep and due to excessive pore pressure thermal spalling occurs [4]. The heat deformation between the mortar and coarse aggregate may reduce the strength [5]. Fiber reinforced concrete (FRC) exposed to high temperatures have results [6,7,8,9,10,11,12] which concluded that FRC has excellent properties as a composite material which can improve flexural, tensile and shear strength, toughness, impact resistance, crack resistance and resistance to frost damage. Micro cracks appear due to shrinkage or applied loads, may be closed with steel fibers that block their growth, after exposure to high temperatures steel fibers may change the cracks spreading, and improve concrete performance[13]. The distribution of steel fibers in RPC affects its mechanical properties and enhance its mechanical performance [14].

Silica fume content affects the cohesion between the RPC base material and steel fibers, cohesive results are optimum when the silica fume contents ranged from 20–30% [15].

Studies [16, 17, 18, and 19]found that RPC enhanced impact resistance and energy absorption ability. The addition of 2% steel fibers with aspect ratio of 65 to the RPC mix improve the tensile strength of composite cementitious materials, also itprovids improvement in the compressive strength [20].

Results showed that in Ultra High Performance Fiber Reinforced Concrete the stress strain curves when concrete reinforced with both hooked and twisted steel fibers are similar to the peak load when it reinforced with hooked steel fibers only [21]. Production of the PVC polymer from crude oil and salt extraction to powder producing the polyvinyl chloride.

3. Experimental Work

Materials

RPC should have properties such as: no coarse aggregate, maximum fine aggregate size between 0.3 to 0.6 mm, high cement content, low water to cement ratio (less than 0.2), pozzolanic materials such as silica fume or any suitable material may be used, to have high flow ability Super plasticizer is used to increase the concrete ductility Steel fibers also used.

1-Silica Fume

It considered one of the most attractive materials used in concrete due to its chemical and physical properties, silica fume can have very high strength and can be very durable. Its uses begins to solve the environmental pollution problems, and have safer and economical construction. It have very large surface area which improves the workability, strength, cracks resistance, permeability and durability and improve the microstructure of the concrete matrix resulting in more stronger and durable concrete. Silica fume in concrete has both engineering potential and economic advantage. Properties of the used silica fume described in tables (1).

Table 1: Properties of silica fume(SF).

Property	Result
Specific Gravity	2.3
Fineness (Blaine)	>1500kg/m2
Physical Form	Powder
Color	Grey
Activity index	>95%
Mix rate	0.1-0.2%
SiO2	90

2-Steel Fiber:

Steel fiber enhances the rigidity, flexural quality, shear and general bendable conduct of cement. They play important role in the reinforcing of concrete construction. Micro steel fibers are used in this research have 0.5 mm diameter, length of 35mm, tensile strength 1000 MPa, aspect ratio of 60 and good heat resistivity.

3-Super plasticizer (SP)

Super Plasticizers are utilized as a part of cement so as to reduce the water bond proportion and improve workability to a more prominent degree. Super plasticizer are used to prevent segregation of particles and to improve the flow ability of concrete materials, its addition to concrete allows to reduce the water to cement ratio without any effect on workability of the mixture, and help to produce self – compacting concrete and high performance concrete. Thus, it improves the total performance of the hardening fresh paste.

4-Polyvinyl chloride (PVC)

Polyvinyl chloride commonly abbreviated PVC may come in the forms: rigid (RPVC) and flexible. rigid form is used in applications such as pipes, profiles, doors and windows. Pure poly vinyl chloride have white colour, brittle solid, insoluble in alcohol but slightly soluble in tetrahydrofuran.

Wastes of PVC are derived from mineral water bottles, credit cards, toys, pipes and gutters, electrical fittings, furniture, folders and pens, medical disposables…. Etc. They are molten on heating at around 100C^o to 260C^o moreover, and then molten PVC possess binding property. Hence, it can be used as a binder and they can also mixed with binder like bitumen to enhance its binding property. This considered a good modifier for the bitumen, used for road construction.

5- Cement:

Ordinary Portland cement used in this research has physical and chemical properties confirmed to the Iraqi specifications limits No.5/1984.

6- Fine aggregate:

Well-graded natural sand used in all concrete mixes with grading lied in (zone No.1) and confirm to the (Iraqi specification No. 45/1984) see table (2).

Table 2: Physical and Chemical properties of sand

Properties	Test Results	I.Q.S.45:1984: Limits
Grading Zone	one	------
Fineness Modulus	2.488	------
Apparent Specific Gravity	2.58	------
Bulk Density (kg/m3)	1850	------
Sulphate Content (SO3)	0.31	0.5 (max.)

Stages of experimental work:-

This research divided into two stages of investigations. **Stage one** represents the first group of tests which have been used to select the most suitable mix to provide high compressive strength with different types of mixes as shown in Fig.(1):

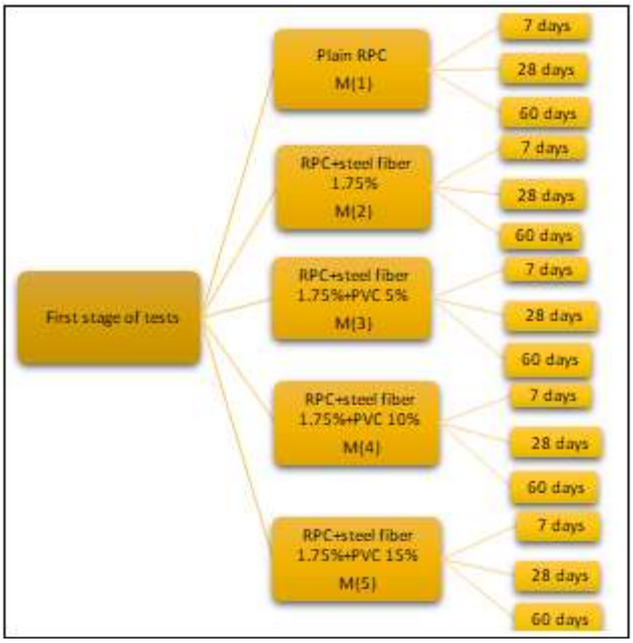


Figure 1: Sketch of the first stage of tests

Stage two:

The second group of tests used the plain reactive powder concrete(RPC), and the RPC with steel fiber of 1.75% and RPC with PVC. Then the election mix from the first stage of the tests exposed to elevated temperature up to 600C^o using closed oven then the specimens were tested for compressive strength.

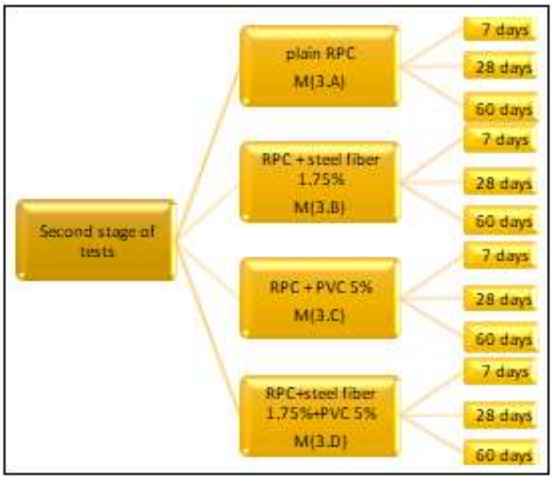


Figure 2: Sketch of the second stage of tests

Mix design:
In the first stage of experiments five mixes were prepared as explained in table(3), 15 cubes of (100*100*100mm) were tested for compressive strength at (7,28 and 60) days.

Table 3: First stage mixes

Mixes	Cement (kg/m3)	Sand (kg/m3)	Water (w/c)=0.22 Lt	S.P Lt	Silica Fume (kg/m3)	Steel Fiber 1.75% (kg/m3)	PVC (kg/m3)
M(1)	750	825	206.36	12	188	-	-
M(2)	750	825	206.36	12	188	16.415	-
M(3)	750	825	206.36	12	188	16.415	47
M(4)	750	825	206.36	12	188	16.415	93.8
M(5)	750	825	206.36	12	188	16.415	140.7

In the second stage of experiments four mixes were prepared as explained in table(4), 12 cubes of (50*50*50mm) were exposed to rising temperature from (0-600C^{o}) for 90 minutes then the specimens were tested for compressive strength at (7,28 and 60) days.

Table 4: Second stage mixes

Mixes	Cement (kg/m3)	Sand (kg/m3)	Water (w/c)=0.22 Lt	S.P Lt	Silica Fume (kg/m3)	Steel Fiber 1.75% (kg/m3)	PVC (kg/m3)
M(3.A)	750	825	206.36	12	188	-	-
M(3.B)	750	825	206.36	12	188	16.415	-
M(3.C)	750	825	206.36	12	188	-	47
M(3.D)	750	825	206.36	12	188	16.415	93.8

Process of RPC mixing
In the first stage mixes were prepared. For each type of mix three (100*100*100mm) cubes casted for three ages (7, 28 and 60 days) see figure (1).

In the second stage mixes were prepared. For each type of the mixes three (50*50*50mm) cubes were casted for three ages (7, 28 and 60 days) see figure (2). The specimens were cured in water for 7, 28& 60 days. For maintaining uniform curing all the specimens are cured in the same curing conditions.

Elevated Temperature and Testing Methodology
Twelve specimens representing four mixes M(3.A), M(3.B), M(3.C) & M(3.D) for three ages (7, 28 and 60 days)were used to represent the effect of a rising temperature on the compressive strength. A control set of heated samples is burned in an electrical furnace (Muffle furnace) of 1500℃ capacity as shown in Figure (3). At 7, 28 and 60 days, the specimens were burned in the furnace for 90min to target temperature of 600℃. After exposure to the temperature, the specimens allowed to be cool at laboratory room temperature for 24 hours then they were tested for compressive strength to assess the residual strength after 1 day.

Figure 3: Samples after and before heating

4. Results and Diagrams

Test results before and after heating were tabulated in table (5) and drawn in figures (4-9)

Table 5: Results of the two stages of tests

Compressive Strength Test for 10*10*10 cm cube						
	Age (days)	Ref. cube (M1) (Mpa)	SF1.75% (M2) (Mpa)	PVC 5% (M3) (Mpa)	PVC 10% (M4) (Mpa)	PVC 15% (M5) (MPa)
	7	40.19	56.01	47	30.6	42.7
	28	48.09	70.45	54.54	45.4	45.45
	60	49.63	81.81	61.36	47.27	60
Compressive Strength Test for 5*5*5 cm cube after burned in the Muffle furnace at 600Co for 90 min .						
	Age	Ref cube	SF 1.75%	Pvc 5%		Pvc + SF

	(days)	(M3.A) (Mpa)	(M3.B) (Mpa)	(M3.C) (Mpa)	(M3.D)(Mpa)
	7	Collapse	48.18	38.18	36.36
	28	Collapse	52.3	42.42	50.1
	60	Collapse	65.64	46.3	57.87

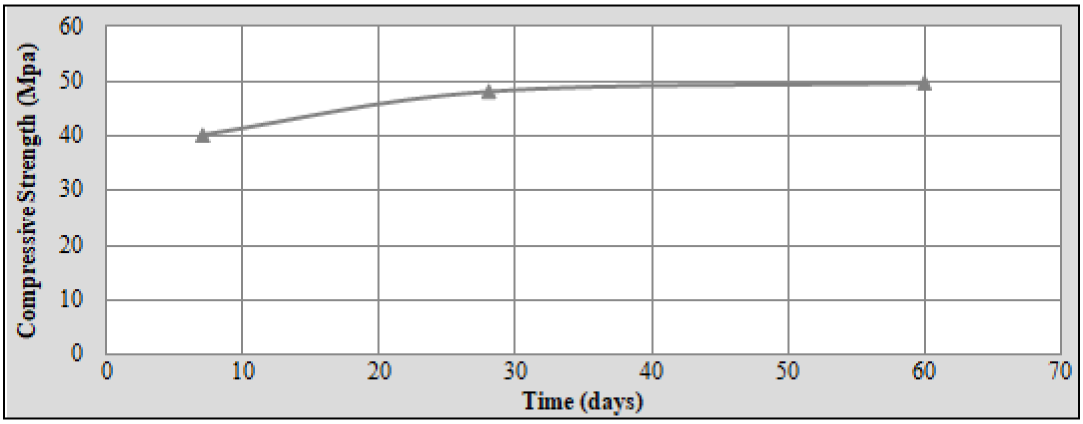


Figure 4: Compressive Strength (Mpa) for (M1) with time

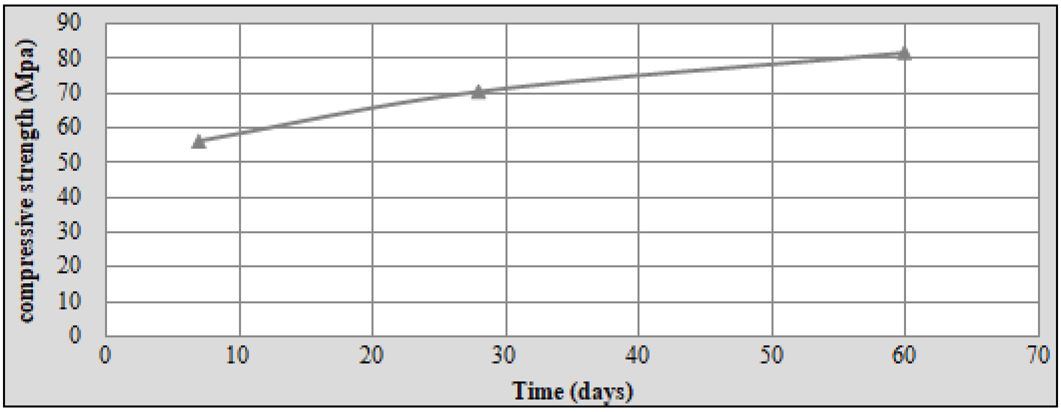


Figure 5: Compressive Strength (Mpa) for (M2) with time

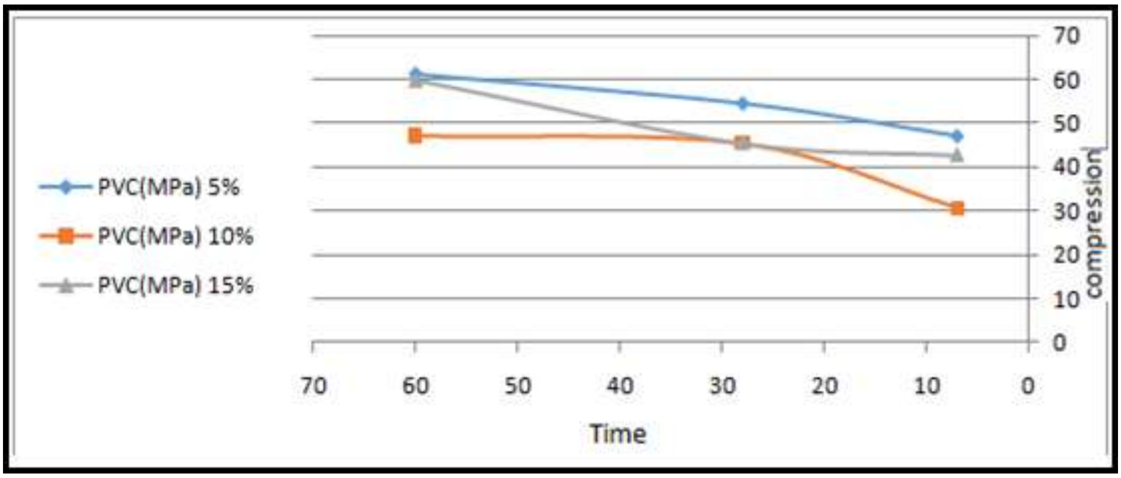
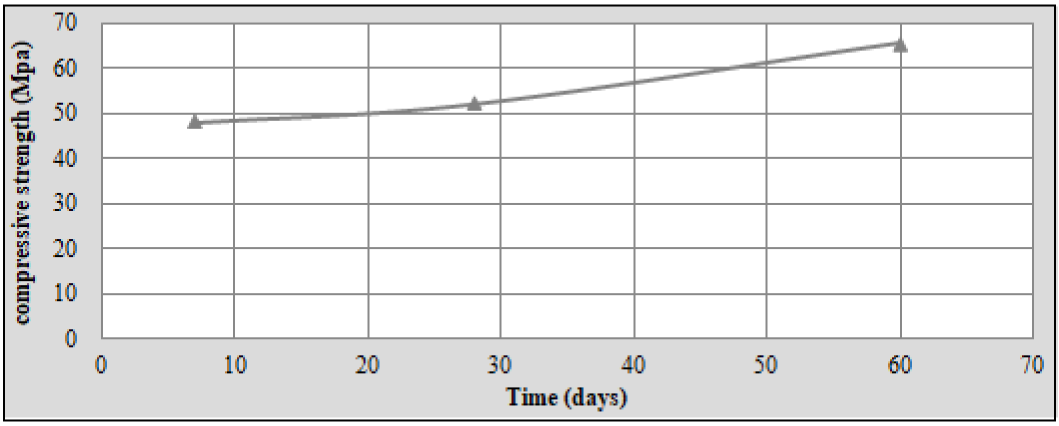


Figure 6: Compressive Strength (Mpa) for (M3,M4 and M5) with time to choose the suitable content of PVC for the second stage



*** plain mix M3.A show dramastic failure**

Figure 7: Compressive Strength (Mpa) for (M3.B) with time

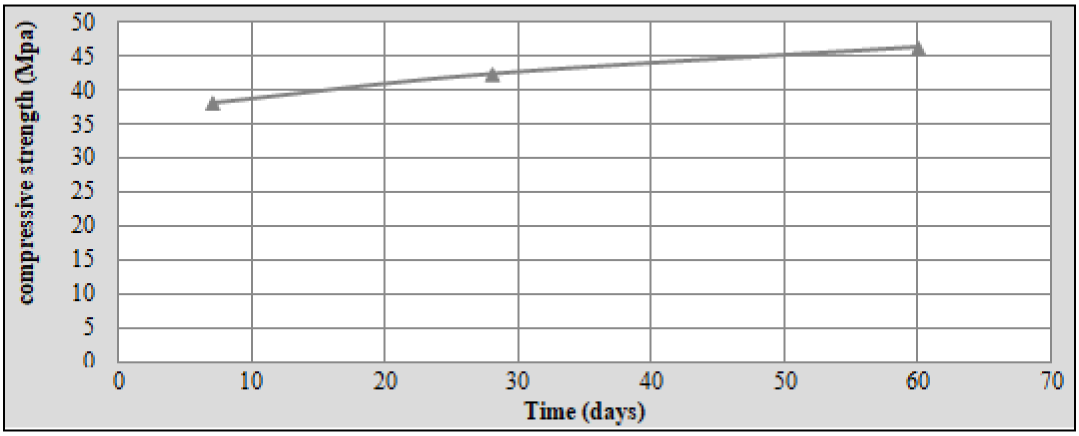


Figure 8: Compressive Strength (Mpa) for (M3.C) with time

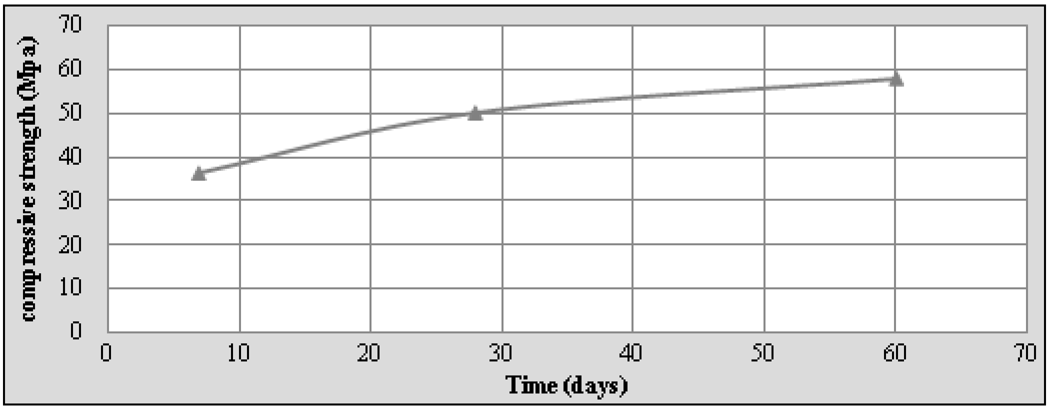


Figure 9: Compressive Strength (Mpa) for (M3.D) with time

5. Discussion

Test results indicated that the composition of reactive powder concrete with steel fiber shows increase in compressive strength with time, while mixes with different proportions of PVC increases in compressive strength with time but at a lower rate than that of steel fiber. Mix(M3) with 5% PVC gives highest compressive strength than 10% and 15% PVC, thus it was chosen to prepare samples that exposed to elevated temperature (0-600C^{o}). The results of mix M(3.A)represents the behavior of reference mix after exposure to elevated temperature which was total collapse after 7,28 and 60 days. But for mix(M3.B) good resistance to elevated temperature after 28 and 60 days, due to the presence of fibers that give low spalling properties for concrete. Mix (M3.D) have good resistance to elevated temperature with lower spalling.

In general, mixes with 5% PVC exhibit highest compressive strength and conventional resistance to elevated temperature by about 5% increase than mix(M3.D) that have (PVC and steel fibers) after 28 days of curing, but with the progress of hydration mix(M3.D) show increase in the compressive strength by about 24% due to the reactivity of silica fume which started to develop strength with hydration slowly and give good compatibility with steel fibers otherwise, mixes(M3.B and M3.D) shows good mode of failure without spalling of concrete when exposed to elevated temperature due to the presence of micro steel fibers that hold the specimens together, in practice this is valuable point to be recognized.

6. Conclusions

1) Generally, concrete gives good fire resistance properties due to concrete composition that is chemically combined and form inert material with low conductivity and good heat capacity.
2) The thermal properties show the capacity of structure to transfer heat.
3) The mechanical properties of concrete show the extent of losing strength and deterioration of stiffness.
4) The deformation determine the progress of deformations and strains in structures.
5) Concrete spalling have important role in fire exposure.
6) All the above parameters may affect the resistance of concrete structures to fire or elevated temperatures.
7) Thermal conductivity decrease with temperature, which depend on concrete mix properties, such as moisture content and permeability and this decrease is due to the variation of moisture content with temperature.
8) Test results show that 5% PVC gives highest composition strength propagation and when mixed with steel fiber it gives good fire resistance.

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