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EFFECT OF WELL WATER ON THE MECHANICAL PROPERTIES OF CONCRETE WITH USING TWO TYPES OF CEMENT

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The effect of using different water resources and cement types on concrete strengths at late ages is investigated. Two types of cement including Ordinary Portland Cement (OPC) and Sulfate Resisting Portland Cement (SRPC) were employed to prepare concrete mixes with potable and well water. Compressive, flexural, and tensile tests on were conducted at 28, 90 and 180 days. Results show that the maximum decreasing of concrete strength was about 42.9% at 180 days compared with the control mix when using well water with OPC. This was due to the chemical contents of well water that are more than the allowed limits. While the reduction in compressive strength was about 31.3% when using well water with SRPC due to sulfate resisting cement. Flexural strength reductions of 50.5% and 42.8% was seen when using OPC and SRPC respectively with well water at 180 days. Same effect was observed for tensile strengths which indicates that using well water has negative effect on concrete strengths at late ages. Modulus of elasticity was calculated using the ACI 318 equation. Higher reduction of 24.5% was seen when using OPC with well water than 17.2% when using SRPC with well water at 180 days compared to control mix.

Keywords: well water, normal concrete, mechanical properties, ordinary portland cement, sulfate resisting portland cement

1 INTRODUCTION

Due to difficulties in obtaining potable water in some areas after wars such as what happened in Mosul City/Iraq in 2017, people depend on water from wells for their daily life demands and constructions (casting and curing) of concrete structures. Since well water has salts, dissolved materials, sulfates and other unfavorable contents, Setting, hardening and strength of concrete are affected by the quality of mixing water [1-2]. Different effects such as steel reinforcement corrosion, staining, efflorescence and decrease in durability may be caused by excessive impurities exist in mixing water [3]. Therefore, percentages of chloride, alkalis, solids, and sulfates should be set in blending water, or convenient experiments must be conducted for impurity impact determination on different concrete merits.

Concrete durability is affected significantly by several impurities while they have little effect on setting time, hence it is important to investigate well water influence on strength and mechanical properties of concrete. Bhamere (2016) showed that using various types of cement including ordinary Portland cement (OPC) and Portland Pozzolana Cement (PPC) resulted in changes in compressive strength at different concrete ages [4]. A study was conducted by Lawrence (2000) to investigate the effect of water type on compressive strength of concrete at ages of 7,14,21 and 28 days. Three types of water were used including saltwater from Abonnema river, freshwater and run-off water from IMSU farm. While strength reduction was recorded at earlier time, it was found that freshwater concrete has acceptable strength with time. The saltwater concrete compressive strength enhanced at the 7th days while a reduction was noticed for the later durations [5].

Sua et al. (2002) prepared mortar specimens with potable water, under- groundwater and wash water. Fluidity, compressive strength and setting time were investigated. Additionally, the slump, unit weight, air content and flow were measured for specimens. It was found that due to pozzolanic reaction activation of the blast-furnace slag and fly ash due to wash water high alkalinity, the growth of wash water concrete strength was much more compared with potable water concrete strength [1].

Influence of seawater used in mixing and curing on strength of concrete at different ages was explored by Geo et al. (2018) it was observed that concrete strength was influenced by seawater when used for mixing and curing showing early strength increment, while strength reduction at later ages. A strength reduction of about 7% was seen in specimens made with freshwater and cured with seawater. While it was observed a strength reduction of 15% when using seawater in mixing and curing compared with using freshwater at 90 days [6]. In (2014) Hassan *et al.*carried an experimental test to examine employing well water from three multiple sites in Mosul city. Concrete mixes were cast with OPC. and SRPC Distilled water was used for making control mixes. The results revealed that the well water with reasonable chemical analysis boundaries was good for acceptable strength concrete production [7].

The influence of water from a well and recycled coarse aggregate used in concrete was investigated by Zidan *et al.* (2019). The well water chemical properties were within standard limits. It was found that the compressive strength reduction for concrete mixed and cured with well water containing natural coarse aggregate was 7.5% compared with concrete that is mixed and cured using potable water. Splitting and flexural strength value reductions were 4.2 % and 2.2%, respectively, when compared with well water. [8]. The effect of mixing and curing various water sources, including river water, deep well water, and rainwater, was investigated by Mohe et al. (2022) [3]. Cement sitting time, workability, compressive, split tensile, and flexural strengths of concrete tests were conducted at 7 and 28days. The improved results in compressive, splitting tensile, and flexural strength were observed when utilizing mixing and curing concrete with river water, potable water, and rainwater.

Meena et al. [9] The use of treated wastewater in concrete as an alternative to potable water was investigated by conducting experimental testing to describe the durability and mechanical properties of concrete made from treated wastewater. Three samples of water were used, including tap water, secondary treated wastewater, and tertiary treated wastewater. Laboratory tests were conducted for each concrete mix, including compressive and flexural strength tests; resistance to chloride penetration; carbonation; and abrasion tests. At different ages, concrete cubes and beams were cast and tested for compressive and flexural strengths as well as durability. When tertiary-treated wastewater is used in place of 100% tap water for mixing concrete and when both tap water and tertiary wastewater are used for curing, the compressive strength is found to be 85-94% of normal concrete. When comparing the curing of concrete using tertiary treated wastewater with tap water and tertiary treated wastewater with tertiary treated wastewater to control concrete, there was a significant improvement in flexural strength.

Expansive chemical reactions in concrete can be observed with the presence of sulfate in groundwater in the form of sodium, magnesium, and potassium salts. Consequently, it causes cracking in concrete, which increases permeability, paving the way for aggressive water to penetrate the concrete. The ability of concrete to resist sulfate attack is affected by the cementitious composition of concrete and the permeability of concrete [10]. Moreover, cement type and water/cement ratio have a substantial effect on the resistance and durability of the concrete [11].

As a result, various studies have been conducted to investigate how effectively water or cement type affects the concrete's mechanical properties. However, the effect of water and cement types together at later ages has not been widely studied. Therefore, this experimental work aims to study the possibility of using well water as mixing and curing water for concrete, using two types of cement to prepare the mixtures, including Ordinary Portland Cement (OPC) and Sulfate Resisting Portland Cement (SRPC). For comparison purposes, potable and well water were used to cast and cure concrete specimens. The specimens were tested at different ages (28, 90, and 180 days) under compression, tension, and bending loads.

2 EXPERIMENTAL METHODOLOGIES

2.1 Materials

This part discusses the materials properties used in this study and experimental program.

2.1.1 Cement

Two types of cement were utilized; Ordinary Portland cement (OPC) produced by (Badoosh Factore) and Sulfate Resisting Portland cement (SRPC) type (Mass Factore) in Mosul City in Iraq. These types were tested according to Iraqi Specifications (IQS NO.5) [12], their physical and chemical properties are illustrated in tables [1-4].

Table1 (OPC) "Badoosh" chemical properties.

Chemical Composition	Value (%)	Standard (IQS, No.5, 2018) (%)	Chemical Composition	Value (%)	Standard (IQS, No.5, 2018) (%)
CaO	60.51	....	L.S.F	0.95	0.66-1.02
SO_3	1.59	(2.8) max	Loss on Ignition	1.94	(4.0) max
Fe_2O_3	3.51	....	Solid solution	16.06	....
SiO_2	20.34	....	C_3A	5.00	....
MgO	2.27	(5.0) max	Free Lime	0.56	....
C_3S	47.65	....	Insoluble Residue	0.44	(1.5) max
AL_2O_3	4.8	....	C_4AF	10.86	....
C_2S	22.37	....			

Table 2 (OPC) "Badoosh" physical properties.

Property	Test Result	Limit of Iraqi Specification (IQS, No.5, 2018)
Initial setting time (min.)	90	≥45
Final setting time (hr)	4.5	≤10
Fineness (m^2/Kg)	325	≥230
Compressive strength (MPa) :(3days) :(7days)	26.0 30.6	≥15 ≥23

Table 3 (SRPC) " Mass " chemical analysis.

Chemical Composition	Value (%)	Standard (IQS, No.5, 2018) (%)	Chemical Composition	Value (%)	Standard (IQS, No.5, 2018) (%)
CaO	62.7	....	L.S.F	0.97	0.66-1.02
SO_3	1.86	(2.8) max	Loss on Ignition	1.67	(4.0) max
Fe_2O_3	4.27	....	Solid solution	15.58	....
SiO_2	18.0	....	C_3A	6.79	....
MgO	4.24	(5.0) max	Free Lime	0.58	....
C_3S	69.7	....	Insoluble Residue	0.97	(1.5) max
AL_2O_3	4.52	....	C_4AF	12.36	....
C_2S	2.31	....			

Table 4 (SRPC) „Mass**"** physical properties

Property	Test Result	Limit of Iraqi Specification (IQS, No.5, 2018)
Initial setting time (min.)	105	≥45
Final setting time (hr)	4	≤10
Fineness (m^2/Kg)	300	≥230
Compressive strength (MPa) :(3days) :(7days)	22.6 38.5	≥15 ≥23

2.1.2 Fine Aggregate

Natural brown sand available in Mosul city known as Kanhash was used. It has 4.75 mm maximum size, 1.6% absorption and 2.61 specific gravity saturated surface dry (SSD) Grading within British specifications (BS.882)[13] boundaries was used. Fig.1 represents its grading.

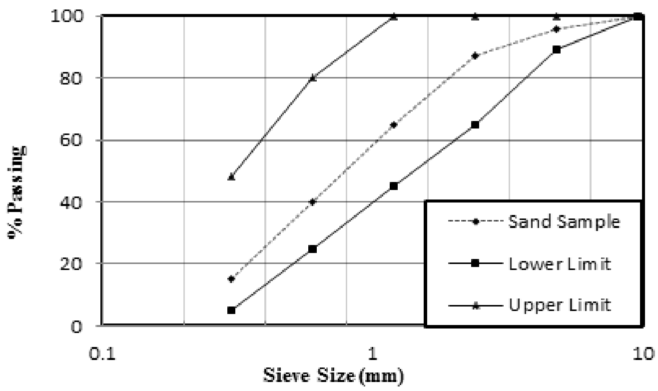


Fig. 1 Fine aggregate grading.

2.1.3 Gravel

The maximum size of the natural, rounded gravel used was 19 mm. It was obtained from Tigris River, Mosul-Iraq and is called Bahes as shown in fig.2. It has 1.0% absorption and 2.66 specific gravity saturated surface dry (SSD) This coarse aggregate was graded according to the limits of American standard testing materials ASTM C33/C33M [14]. Fig.3 represents its grading.

Fig. 2 sample of coarse aggregate

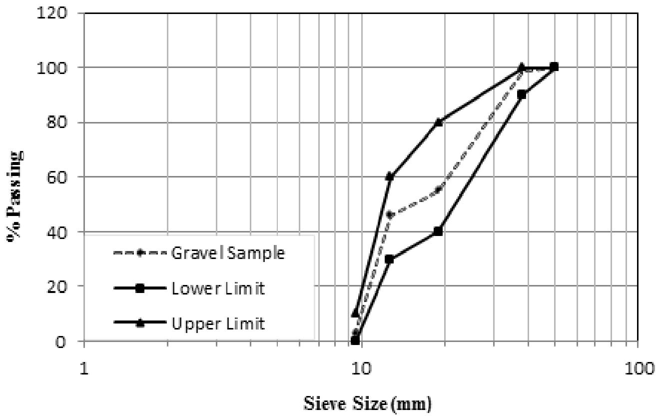


Fig. 3 Grading of coarse aggregate

2.1.4 Water

Two types of water including potable water(PW) and well water(WW) were utilized for mixing and curing of concrete specimens. Well water was taken from a well with a depth of 60.0 m. It was tested and its chemical compound were compared with American standard testing materials ASTM C94/C94M [15] standard limits. Table 5 shows the obtained results.

Table 5 Well water chemical analysis.

Chemical compounds (mg/L)	ASTM (C 94) Limits (maximum concentration, ppm)	Well water
Chloride, as Cl	500	660
pH		7.4
Sulfate, as SO_4	3000	1800
Magnesium, as Mg		112
Calcium, as Ca		1300
Total Solids	50000	3880
Total dissolved solids		3670
Alkalis, as Na_2O+0.658 K_2O	600	440
Conductivity		6338.8

2.2 Mix Proportions and Specimens Preparation

In total, four mixes of concrete were cast. The first mix was a control mix made by Ordinary Portland Cement with potable water as mixing and curing water. The mix Proportions was (350:725: 105/120), the water-cement ratio was kept constant for all mixes to keep the slump values between 80-100 mm [16]. Table 6 shows the details of the mixes.

Table 6 Mixes of Concrete with its components

Mix No.	Mix ID	Mixing Water	Curing Water
Mix 1(control)	OPC + PW	PW	PW
Mix 2	OPC+WW	WW	WW
Mix 3	SRPC+PW	PW	PW
Mix 4	SRPC+WW	WW	WW

Standard cubes for concrete compressive strength tests were utilized with 150 mm dimensions, Standared cylinders of (100x200) mm were used for the split tensile strength test, and for the flexural strength test, beams of (100x100x500) mm were used. The mixes were cast and kept for 24 hours. After the curing process and for each mix of concrete, 3 samples of each test were tested at 28, 90, and 180 days according to BS1881: Part 116 specifications [17] for compressive strength, ASTM C496/C496M specifications [18] for split tensile strength, and (ASTM C293/C293M) specifications [19] for flexural strength. Fig. 4 shows the procedure of testing.

(a) (b) (c)

Fig. 4 Experimental setup for (a) compression test (b) Splitting tensile Test (c) flexural test

3 RESULT OF THE ANALYSIS AND DISCUSSION

3.1 Compressive Strength

For all mixes, the results of mechanical properties including compressive, tensile and flexural strengths showed in table (7). Compressive strength at (28) days were close because the alkalis in well water accelerate the hydration of cement at early ages. The compressive strength increased for the control mixes, mix1 with (OPC+PW) and mix3 with (SRPC+PW) by 21.8%, 23% at 180 days respectively. While it decreased for mix2 with (OPC+WW) and mix4 with (SRPC+WW) by 25%, 12.5% at 180 days respectively, the reason behind that was the use of well water, which has a negative effect on the compressive strength of concrete when it is compared to potable water [8-20]. Water impurities that conflict with the setting of cement influence concrete durability and strength negatively. This is caused by chemical constituents found in water which may affect the setting, hardening, and concrete's strength. [21]. Moreover, the concentration of Sulfate (SO_4) was 1800 ppm in well water has aggressive effect on compressive strength [22]. The effect of cement and water types used in all mixes on compressive strength was observed. The results showed decreasing of compressive strength while using well water with a higher ratio of 43% in the mix2 with OPC than in a mix4 of 27%, with SRPC. at 180 days, because of using of (SRPC) which resists the effect of sulfate (SO_4) in well water and other components as (Cl). The use of new and supplementary cementing materials in recent decades enhanced some aspects of concrete durability [23]. Mix2 had the greatest loss in compressive strength. due to the OPC binder attack technique caused by magnesium sulfates and sodium presents in well water. This is essentially due to the following factors:

a) Gypsum creation caused by sulfates and calcium hydroxide resulted from the hydration of cement, [24-25]

b) Ettringite creation caused by calcium aluminate or mono sulfates and gypsum [24-25].

Fig.5 table 7 ,8 shows the results of compressive strength for the four mixes.

Table 7 The Mechanical Properties of Concrete Mixes

Mixes	Age (days)	Compressive strength (MPa)	Splitting Strength (MPa)	Flexural Strength (MPa)	Modulus of Elasticity (MPa
Mix1(Control) (OPC+PW)	28	41.7	3.2	7.83	28400
	90	44.2	3.45	9.0	29300
	180	50.8	3.9	10.3	31400
Mix2(OPC+WW)	28	39	2.8	6.4	27500
	90	35	2.65	5.9	26000
	180	29	2.32	5.1	23700
Mix3(SRPC+PW)	28	39	3.0	7.5	27500
	90	42	3.3	8.8	28500
	180	48	3.65	9.8	30500
Mix4(SRPC+WW)	28	40	2.8	6.8	27900
	90	37	2.7	6.4	26800
	180	35	2.6	5.9	26000

Table 8 The % Reduction in Mechanical Properties of Concrete Mixes

Mixes	Age (days)	Compressive strength (MPa)	Splitting Strength (MPa)	Flexural Strength (MPa)	Modulus of Elasticity (MPa)
Mix1(Control) (OPC+PW)	28	-	-	-	-
	90	-	-	-	-
	180	-	-	-	-
Mix2(OPC+WW)	28	6.4	12.5	18.3	3.2
	90	20.8	25.1	34.4	11.3
	180	42.9	40.5	50.5	24.5
Mix3(SRPC+PW)	28	6.4	6.2	4.2	3.2
	90	4.9	6.7	2.2	2.7
	180	5.5	6.4	5.1	2.9
Mix4(SRPC+WW)	28	4.0	12.5	13.2	1.8
	90	16.2	23.7	28.9	8.5
	180	31.3	33.3	42.8	17.2

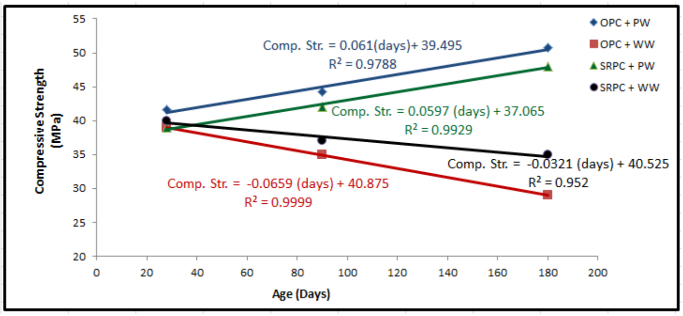


Fig. 5 Change of compressive Strength with time.

3.2 Splitting Tensile Strength

For the control mix with Ordinary Portland Cement and Potable water (OPC and PW) the splitting tensile strength increased with time. The percentage of increasing was about 11%, 21.8% at 90 and 180 days respectively. Also, for mix3 with (SRPC and PW), the splitting tensile strength increased with time with a ratio of 10%, and 21.6% at 90 and 180 days respectively. This was because the potable water that has no negative effect on mechanical properties of concrete.

The splitting tensile strength for mix2 (OPC + WW) decreased with time at 28 and 90 days and reached to the lowest values at 180 days. The percentage of reduction was about 41% compared with control mix1. The reason behind that was using of well water, the potable water indicates higher strength than groundwater water [26].For mix4 (SRPC+WW) the splitting tensile strength decreased because of well water, however, the reduction in splitting tensile strength was lower than the reduction in splitting tensile strength in mix2. This was because of using of (SRPC) which resist the effect of sulphate (SO_4) in well water , the concrete develops porous with groundwater [26] which makes concrete weaker. Fig.6 shows the results of splitting tensile strength for the four mixes.

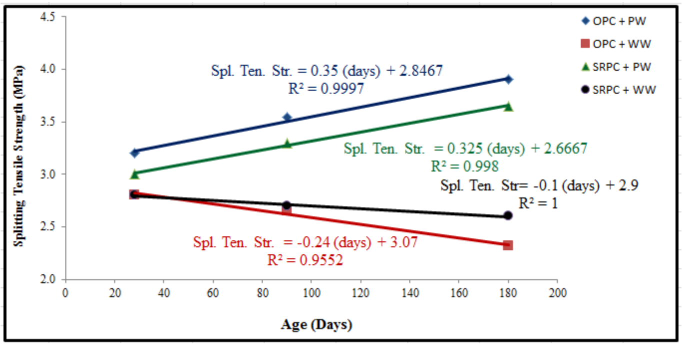


Fig. 6 Change of splitting Tensile Strength with time.

3.3 Flexural Strength

Like compressive and tensile strength, specimens' flexural strength cast and cured with well water reduced with time compared with the control mix. The percentage of reduction was about 18.2%, 34%, 50% at 28, 90 and 180 days respectively. The reduction of flexural strength for mix2 (OPC and WW) was higher than mix4 because the OPC doesn't have the property of sulphate, chlorides and alkalis resistance in well water, shows less sensitive to the variation in water type than flexural strength [25]. Fig. 7 shows the values of flexural strength for the four mixes.

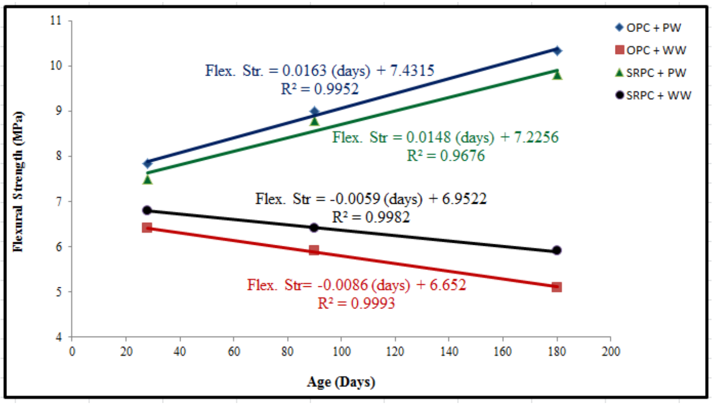


Fig.7 Change of Flexural Strength with time

It is noted that flexural and splitting tensile strengths are increasing when compressive strength increases. Hence, high correlation coefficients were acquired (Figs. 8 and 9).

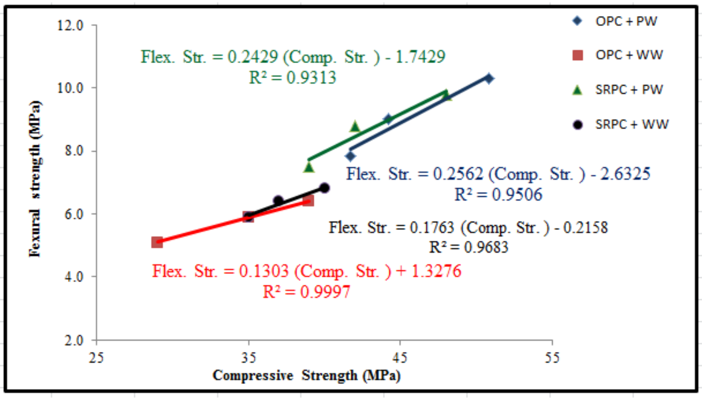


Fig. 8 Correlation between (compressive and flexural strength)

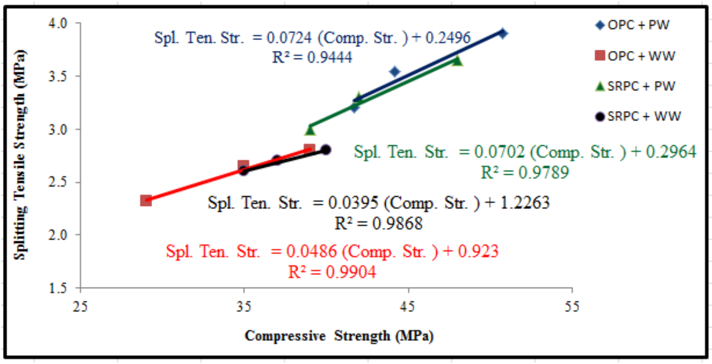


Fig. 9 Correlation between (compressive and tensile strength)

Concrete tensile strength were obtained using flexural and splitting tensile strength, there is a parallel manner between it and the flexural strength as shown in Fig. 10.

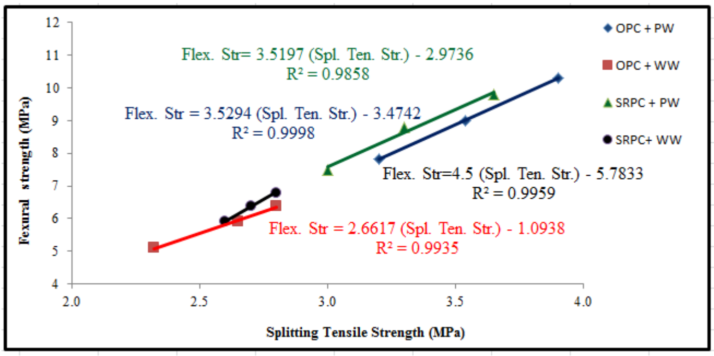


Fig. 10 Correlation between (flexural and tensile strength)

3.4 Modulus of Elasticity

Physically, it is stress impedance by the material, and it can be defined as material stiffness indicator, where stiffer materials have higher elastic modulus. Additionally, several codes accommodate empirical formulas for elastic modulus evaluation, which are basically instituted on concrete compressive strength and the elastic modulus, where approximate estimate of modulus of elasticity can easily be found via (28 days) concrete strength. Fig. 11 explained the modulus of elasticity of the mixes which estimated by using ACI318 [27] equation based on the measured fc as shown below.

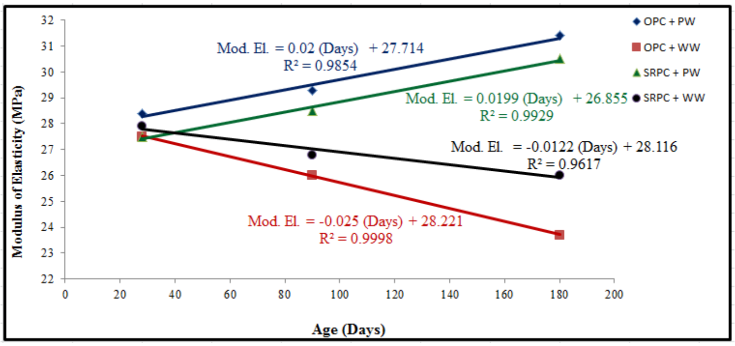


Fig. 11 Change of modulus of elasticity with time.

By noting the correlation in Fig. 12 between the modulus of elasticity and the compressive strength, it is evident that they are proportional to each other; high correlation values therefore were observed.

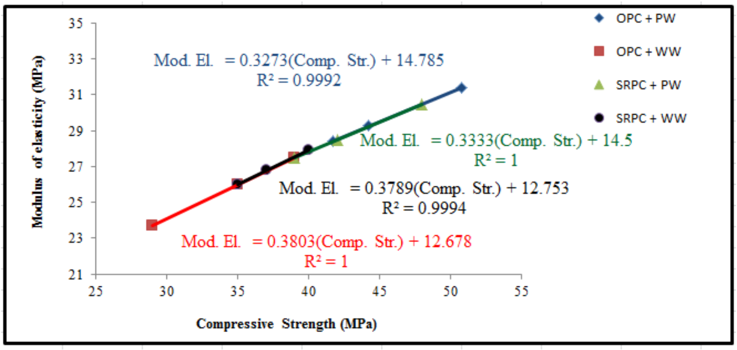


Fig. 12 Correlation between (compressive strength and modulus of elasticity).

The color of samples, which were cured in well water, was changed to white due to the formation of whitish layer on specimens' surface as shown in Fig. 13. This happened because of salt content in well water which agreed with [28].

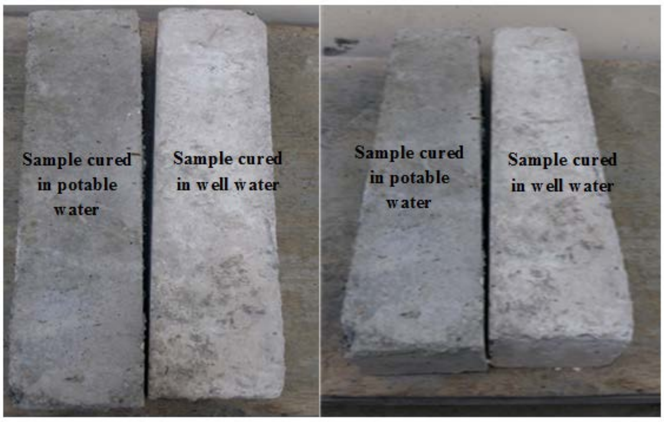
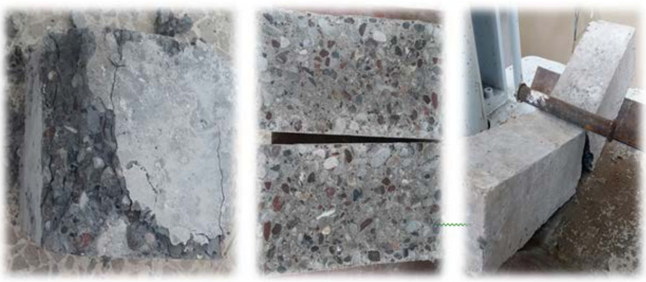


Fig. 13 The difference in colors of the sample.

Samples (Cubes, Cylinders and Beams) were tested according to the previously mentioned specifications. Table 9 showed the results and Fig. 14 showed the failure of samples for compression, splitting and flexure.



(a) (b) (c)

Fig. 14 Failure in Specimens for (a) compression (b) splitting (c) flexural

The results showed that the use of well water with properties out of water standards used in construction decreases concrete mechanical properties. This water comprises alkalis sulfates chlorides which may be harm for concrete [29], when water includes high concentration of sodium and potassium that cause a dangerous reaction between alkali and aggregate, it will be unsuitable for mixing water utilization. While the potable water usage is mostly insured [30], especially if the Ordinary Portland Cement (OPC) used. The decrease in mechanical properties of concrete with time by using (SRPC) was lower than utilizing (OPC). Table 9 showed the results of mechanical properties for all mixes. The reduction in modulus of elasticity values for (OPC and WW) mix was the highest. They were 3.2%, 11.3% and 24.5%, while (SRPC and WW) mix showed (1.8%, 8.5% and 17.2%) at (28, 90 and 180) days, respectively.

4 CONCLUSION

In this study the well water influence on concrete mechanical properties was investigated and compared with potable water by utilizing (OPC) and (SRPC), the results showed the following:

- When using potable water in concrete mixing and curing, compressive, splitting tensile, and flexural strengths were improved compared with well water.
- Durability of concrete was affected when using well water. Compressive, splitting tensile, flexural strengths and modulus of elasticity decreased with time.
- The higher compressive strength reduction percentages were found in (OPC and WW) mix, they were (6%, 20.8% and 42.9%), while (SRPC and WW) mix marked (4.0%, 16.2% and 31.3%) at (28, 90 and 180) days, respectively.
- All water intended to be used for production of concrete must be evaluated to make sure it conforms to the laid down standards.
- The decrease in mechanical properties of concrete with time by using (SRPC) was lower than utilizing (OPC).
- The loss in splitting tensile strength values was noticeable for mixes cast and cured with well water especially by using (OPC), they were (12.5%, 25.1% and 40.5%), while (SRPC and WW) mix marked (12.5%, 23.7% and 33.3%) at (28, 90 and 180) days, respectively.
- The (OPC and WW) mix presented the highest reduction values in flexural strength, they were (18.3%, 34.4% and 50.5%), while (SRPC and WW) mix recorded (13.2%, 28.9% and 42.8%) at (28, 90 and 180) days, respectively.
- The reduction in modulus of elasticity values for (OPC and WW) mix was the highest also, they were (3.2%, 11.3% and 24.5%), while (SRPC and WW) mix showed (1.8%, 8.5% and 17.2%) at (28, 90 and 180) days, respectively.
- Several relationships were proposed between concrete mechanical strengths and the durations in a (linear) mode for the samples included two types of cement and two types of water, good correlations were obtained with the experimental results.

5 ACKNOWLEDGEMENT

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