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Original Research Article

Effect of Citrate Salts of Li+, Na+ and K+ on Some Physical Properties of Ordinary Portland Cement (OPC)

Zaki N. Kadhim^{1*}, Alaa K. Ibraheem², Mohammed J.

Al-assadi¹

¹Chemistry Department, College of Science, University of Basrah, Basrah, Iraq ²Um-Qsir Cement Factory, Basrah, Iraq

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*Corresponding author

Zaki N. Kadhim, Chemistry Department, College of Science, University of Basrah, Basrah, Iraq Tel: +964-7801397186 Email: zekinasser99@vahoo.com

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Abstract

The citric acid was used as a water reducer, setting time retarder and workable time extender admixture on ordinary Portland cement (OPC). The changes in compressive strength, permeability and rebar corrosion upon addition of this admixture were studied.

The study also explores the effects of citric acid, tri-lithium citrate, tri-sodium citrate and tri-potassium citrate on most of the physical properties of the ordinary Portland cement type 1 (OPC) produced by Basrah cement factory /IRAQ. Thus, the compressive strength, standard consistency and setting time tests were performed. The results showed increasing in compressive strength in age 28 days, when low dosages (approximately $\leq 0.2\%$) of all types of admixtures were used. Standard consistency results showed a correlation between amount of admixtures and reducing water demand to reach standard consistency. The Setting time test showed the low dosages of all admixtures prolonged the thickening to a certain extent, while the large amounts were caused a remarkable reduction. The increasing in strength in a small number of admixtures may be attributed to the hardened cement specimens. An improvement in permeability and rebar corrosion, also, was observed when certain ratios of admixtures have been used.

Abbreviations: OPC: Ordinary Portland Cement; CSH: Calcium Silicate Hydrate; C₃A: Tricalcium Aluminate; CAH: Calcium Aluminate Hydrate; XRF: X-Ray Fluorescence; ASTM: American Society for Testing and Materials

INTRODUCTION

In strictly chemical terms, hydration is a reaction of an anhydrous compound with water, yielding a new hydrated compound. In cement chemistry, hydration is understood to be the reaction of a non-hydrated cement or one of its constituent with water, associated with both chemical and physico-mechanical changes of the system, with setting and hardening when water is added to cement, paste is formed which gradually stiffens and then hardens. The stiffening of cement paste is called setting. Normal setting of cement is associated with the hydration of Alite (impure C_3S) and formation of the calcium silicate hydrate (CSH) phase and hydration of tricalcium aluminate (C_3A) where react with water immediately forming different calcium aluminate hydrates (CAH) [1]. Setting, in general, depends on type of cement and the water/cement (w/c) ratio.

Hot weather is defined as any combination of high temperature (generally above 80 degrees F (26.7°C), low relative humidity, and wind velocity tending to impair the quality of fresh or hardened concrete or otherwise resulting in abnormal properties, so concrete surface shall not be allowed to dry after placement and during the curing period by increasing the water content or by adding admixture. The water content of a freshly mixed batch of concrete has important consequences

on the properties of the concrete. Addition of overload water will produce in higher porosity, lesser potency and poorer toughness. Consequently, control of the water to cement $(w\c)$ ratio is a crucial part of process manage throughout concrete batching [2-4]. Thus, to avoid concrete from the undesirable effects of hot weather, admixtures are normally incorporated in it [1]. The effect of hot climate of south Iraq was characterized by high ambient temperature and high wind speed. This demand using water reducer and retarder admixture to improve physical properties of concrete to reduce the intensity of reduction in water content and drving shrink. However, the amount of shrink is influenced the most by removal of water from the smaller capillary void, and compressive strength is more an indication of the volume of the voids and not the pore size distribution and to offset unwanted effect of high temperature, such as acceleration of set and reduction of 28-day compressive strength, and to keep concrete workable during the entire placing and consolidation period [5]. In the literature, various water-reducers\ retarders admixtures were found such as sugars [6,7], cellulose ethers [8,9], lignosulfonic acid [10,11], citric acid [12-15], gluconates [16], dextrins [17], and calcium sulfate [18].

The retarders most widely used in practice appear to be hydroxyl carboxylic acid or citric acid and it's salts classified as water-reduce and retarder admixture (ASTM C 494 Type A, D)

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[19]. Since citric acid has a retarding effect on the hydration in the system C_3A -gypsum-portlandite-water [20], where the citrate ions are powerful chelators of solution Ca^{2+} and Al^{3+} and would be expected to influence the nucleation and growth of phases containing these ions so that the chelator molecules citrate, as expected, affected the nucleation of the ettringite [21,22]. However, other investigations which provided the mechanisms of the retardation suggested that citrate sorbet onto the clinker grains, while their dissolution and the chelation or complexation of the ions was found as a weak mechanism [23].

The main objective of this study is to test the effect of citric acid and their Li⁺, Na⁺ and K⁺ salts on the strength, water demand, setting time and other properties of the cement (OPC) type1.

MATERIALS AND METHODS

Type of cement

All experiments were carried out using ordinary Portland cement type 1 (OPC) that was produced by Basrah cement factory/IRAQ. The composition of the unhydrated cement and the calculated amount of the clinker phase are shown in (Table 1). The chemic composition of the unhydrated cement was determined by X-ray fluorescence (XRF) type Minipal spectrometer and by classic analyses. The Blain surface area of the cement was 3334 cm²/g (516.771 square inches).

Types of admixture

The citric acid that has been used in this work was a food grade, while the corresponding salts were prepared from by direct acid-base reaction, Thus, it has been carried out by addition of an alkaline Li, Na and K metal bases to citrate acid solutions (pH: 6.5 - 8.0). The resultant precipitate was recovered by addition of ethanol [24,25].

Compressive strength of mortars

The compressive strength tests were conducted under standard conditions, following the Iraqi standard IOS 198-1990 [26] and B.S 12: part: 1971. Accordingly, the cubes samples were used with dimensions of 70.7×70.7×70.7mm (2.783×2.783×2.783 inches) (50 cm^2 cross section (7.75 square inches)). The samples were prepared by using a vibrating machine, and mixed mechanically conforming to ASTM C 305-99 (standard practice for mechanical mixing of hydraulic cement pastes and mortars of plastic consistency) [27]. The samples prepared by using citric acid and its salts at different concentrations (as wt. % of cement) on three replicate mortar specimens. Eleven samples have been prepared with increments of [0.025-0.050] for each admixture. The proportion of materials for the standard mortar was one part of cement to three parts of standard sand with water to cement ratio of 0.4%. The measurements for hardness were tested using a 250 KN capacity compression machine with a digital indicator type ELE International-ADR auto. Tests were performed at ages of 3, 7 and 28 days, the average value of each set was recorded.

Vicat apparatus Test

Vicat apparatus was used for determination of both: the standard consistency and setting time of paste per Iraqi standard specification IOS 198-1990 which is almost corresponds to the ASTM C 187-98 [28] and C 191-04 [29]. The normal consistency pastes have been made by mixing of 400g $(0.39 \times 10^{-5}$ imperial ton) of dry OPC with a variable percentages of water content for 4 min followed by addition of the admixtures with a variable percent. The used mould was a 90 mm (3.543 inches) in diameter at base and 80 mm (3.15 inches) at top with a conical shape. Technically, the paste normal consistency was established when the Vicat plunger of 10 mm (0.394 inch) diameter penetrate the paste to a point 5-7 mm (1.97- 0.276 inch) from the bottom of the mould within 30 sec period.

The initial setting times were measured by using pastes prepared in the same manner above, with replacement of the plunger by a needle of 1 mm (0.0394 inch) in diameter and 4 mm (1.57 inch) long, set on the lower end of the rod. The rod was released for 30 sec and time at which the needle was released has been noted. Thus, this operation was repeated until the penetration of the needle in the paste became just at 5 mm above the bottom. The total time was calculated to be as the initial setting time.

The later procedure was conducted to determine the final setting time but with employment of 5 mm (1.97 inches) needle and the time was recorded when the released needle did not sink visibly and left no impression on the surface of the paste. Setting times with varying admixtures contents were performed under the specified curing conditions.

Absorption after immersion test

The effect of the admixtures on the absorption of water by cement were studies. This process was carried out according to the ASTM C 642 [30] standard test method for density, absorption, and voids in hardened concrete. Three models (each model contains 0.15% of admixture plus OPC) were prepared for each examination. Thus, the model has immersed in water (humidity chamber) and left for 28 days then placed in the oven for 24 hrs at 100-110 °C for 24 hrs. After cooling to room temperature, model was weighed then submerged again in water for 48 hrs followed by removal of the moisture from the surface and reweighed. The following equation (1) was useful to determine the amount of absorbed water after immersion.

A= mass of surface-dry sample in air after immersion, g

C= mass of surface-dry sample in air after immersion and boiling, g

Determining the Corrosion Activity by Using Half-Cell Potentials Method

A copper-copper sulfate half-cell has been made according to ASTM C 876 Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete, to evaluate the amount of corrosion occurring to rebar in concrete. This has been done by taking rods rebar steel of length of 17 cm (6.693 inches) and a diameter 16 mm (0.63 inches), cleaned them, turning edges to install mains then submerging them partially in a solution rich with chloride ions.

RESULTS AND DISCUSSION

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Addition of citric acid to the (OPC) caused an increasing in strength at concentrations below (0.15, 0.25 and 0.35%) within 3, 7 and 28 days respectively, compared to the controlled cement samples. The best results have been obtained when dosages 0.1% admixture were used, as shown the results are shown in (Table 2).

Table 1: Composition of cement

Chemical	Chemical analysis (g/100g)									
SiO ₂	Al ₂ 03	Fe ₂ O ₃	Ca0	SO ₃	L.O.I.	Na ₂ Oeq	Free.CaO	Ins.res.		
20.90	5.00	3.40	62.90	2.20	0.90	0.68	1.20	0.40		
Other pai	rameters									
SM	AM	L.S.F.	C ₃ S	C ₂ S	C ₃ A	C ₄ AF	Mg0			
2.49	1.47	91.95	47.55	24.13	7.50	10.34	4.00			

Table 2: Compressive strength of cement with various citric acid content

Symbol	Admix- ture	Percent- age	Compressive strength (KN mm ⁻²)			Percentage of change in strength			
			3 Days	7 Days	28 days	3 days	7 days	28 days	
H1	Control	0%	21.6	28.5	38	0	0	0	
H2	HC	0.025%	22.6	28.9	39.4	4.4	1.4	2.8	
H3	НС	0.050%	24.3	31.5	41.5	11.1	9.5	7.7	
H4	НС	0.075%	25.4	31.7	42	15	10.1	8.8	
H5	НС	0.100%	26.5	31.8	43.3	18.5	10.4	11.5	
H6	НС	0.150%	23	32.4	41.3	6.1	12	7.3	
H7	HC	0.200%	21.7	30.9	41	0.5	7.8	6.6	
H8	HC	0.250%	20	29.1	39.5	-8	2.1	3	
H9	HC	0.300% *	18.5	27.8	39	-16.8	-2.5	1.8	
H10	HC	0.350% *	13.9	28	39.6	-55.4	-1.8	3.3	
H11	НС	0.400% *	12.8	28.4	37.8	-68.8	-0.4	-1.3	
Abbrev [31] bec	iations: *I cause retar	n this conce ded effect o	entration on early h	keep tes ydration	t specime of the HC	ns in the (citric a	e molds 4 icid adm	8 hour ixture).	

Addition of tri-sodium citrate admixture to the (OPC) increased the strength at concentrations below (0.2 %) and (0.25%) on 3, 7 and 28 days periods respectively. Good results have been obtained when (0.15%) admixture was used, showing its retardation property only at high dosages over the age of 3 days. These results are presented in (Table 3).

When tri-potassium citrate was used as admixture, the strength increased at all selected concentrations on day 7 and 28 compared to the control. Also, we observed that the salt clearly acts as a retarder at all selected concentrations at age of 3 days, the results are shown in (Table 4). Using tri-lithium citrate as admixture showed increasing of strength at all selected

concentrations at ages of 7 and 28 days. The retardation ability of this salt has been observed at all selected concentrations in 3 days, results are shown in (Table 5).

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Symbol Admix- ture		Percent-	Compressive strength (KN mm ⁻²)			Percentage of change in strength		
			3 Days	7 Days	28 days	3 days	7 days	28 days
N1	Control	0%	21	28.9	38.5	0	0	0
N2	NC	0.025%	22.5	31	40.3	6.7	6.8	4.5
N3	NC	0.050%	22.6	31.4	41	7.1	8	6.1
N4	NC	0.075%	23	31.5	41.2	8.7	8.3	6.6
N5	NC	0.100%	23.4	31.8	41.7	10.3	9.1	7.8
N6	NC	0.150%	24.2	32.8	44	13.2	11.9	12.5
N7	NC	0.200%	24.1	32.4	41.8	12.9	10.8	7.9
N8	NC	0.250%	22.1	31.3	39.5	5	7.7	2.5
N9	NC	0.300%	20.9	28.9	38.7	-0.5	0	0.5
N10	NC	0.350% *	19.1	28.4	38	-9.9	-1.8	-1.3
N11	NC	0.400% *	17.7	27.3	36.6	-18.6	-5.9	-5.2
In this co	naantrati	ion koon to		on n tho	molda 40	hour [2]	lhogou	a notand

In this concentration keep test specimen n the molds 48 hour [31] because retarded effect on early hydration of the mortar NC (Tri-sodium citric acid admixture).

Table 4: Compressive strength of cement with various tri-potassium citric content

Symbol	Admix- ture	Admix- Percent- ture age		ressive st (KN mm ⁻²	crength ²)	Percentage of change in strength		
			3 Days	7 Days	28 days	3 days	7 days	28 days
K1	Control	0%	21.1	28.3	38.7	0	0	0
K2	KC	0.025%	16.7	27.2	39.6	-26.3	-4	2.3
К3	KC	0.050%	16.9	27.4	41.2	-24.9	-3.3	6.1
K4	KC	0.075%	18	27.5	42.3	-17.2	-1.4	8.5
K5	KC	0.100%	19.2	29.5	41.7	-9.9	4.1	9.4
K6	KC	0.150%	19.8	28.5	43.6	-6.6	0.7	11.2
K7	KC	0.200%	18.3	27.9	44	-15.3	-1.4	12
K8	KC	0.250% *	17.2	26.4	38.8	-22.7	-7.2	0.3
К9	KC	0.300% *	15	25.9	37.1	-40.7	-9.3	-4.3
K10	KC	0.350% *	17.1	23.5	34.3	-23.4	-20.4	-12.8
K11	KC	0.400% *	21	20.3	31.7	-0.5	-39.4	-22.1

In this concentration, keep test specimens in the molds 48 hour [31] because retarded effect on early hydration of the mortar cubs therefore don't enough hardness to remove from the molds. KC: Tri-potassium citrate admixture

According to these results the following order can be set to show the effect of the used admixtures at 0.15 % (best concentration) on the strength of OPC:

a - Effect of citric acid and citrate admixtures in 3 days:

Tri-Sodium citrate > Citric acid > Tri-lithium citrate > control > Tri-potassium citrate

b - at age of 7 days :

Tri-Sodium citric > Citric acid > Tri-lithium citrate > Tri-potassium

citric > control

c - at age of 28 days:

Tri-Sodium citrate > Tri-potassium citrate > Citric acid > Trilithium citrate > control

Symbol	Admix-	Percent-	Comp	ressive s (KN mm ⁻	trength ²)	Perce i	ntage of change n strength	
	ture	450	3 Days	7 Days	28 days	3 days	7 days	28 days
L1	Control	0%	21.6	28	37.8	0	0	0
L2	LC	0.025%	18	29.2	38.3	-20	4.1	1.3
L3	LC	0.050%	18.1	30	.38.5	-19.3	6.7	1.8
L4	LC	0.075%	18.7	30.5	38.6	-15.5	8.2	2.1
L5	LC	0.100%	21	30.8	38.8	-2.9	9.1	2.6
L6	LC	0.150%	21.4	31.8	39.3	-0.9	11.9	3.8
L7	LC	0.200%	20.5	31.7	41.8	5.4	11.7	9.6
L8	LC	0.250%	20	30.5	39.4	-8	8.2	4.1
L9	LC	0.300% *	19.4	30.1	39.1	-11.3	7	3.3
L10	LC	0.350% *	19	31.2	39	-13.7	10.3	3.1
L11	LC	0.400% *	21	33.2	38.8	-2.9	15.7	2.6
		_						

Table 5: Compressive strength of cement with various tri-lithium citric cement

In this concentration, keep test specimens in this molds 48 hour [31] because retarded effect on early hydration of the mortar cubs therefore don't enough hardness to remove from the mold. LC: Tri-lithium citric admixture

Table 6 summarizes the compressive strength at concentration of 0.15 % admixtures. However, the results show increasing in the strength at age of 28 days when low dosages (approximately lower than 0.2%) were used for all types of admixture, and the best dosages were found at 0.15% by weight.

 Table 6: Compressive strength (KN mm⁻²) of cement with 0.15 % admixture

			0.15 %	admixtures	
Age of Samples	Control	Citric acid	Tri-sodium citrate	Tri-potassium citrate	Tri-lithium citrate
3 days	21.6	23	24.2	19.8	21.4
7 Days	28	32.4	32.8	28.5	31.8
28 days	37.8	41.3	44	43.6	39.3

The increasing in strength in small amount of admixtures may be attributed to the hardened cement specimens that have a good texture, lower porosity, low air voids, low microcracks, good impact, and regular microstructure. These good mechanical and physical properties come from the high elasticity of cement pastes which may improve the chemical reactions with alkaline oxides ($Na_2O \& K_2O$) or changing the mechanism of the hydration process to modify the hydration morphology.

Table 7 shows decreasing in water demand with increasing concentrations of citric acid and its salts admixtures, which were added to cement to achieve normal consistency.

These results indicate that citric acid and citrates act as water reducers in the following order:

Citric acid > Tri-lithium citrate > Tri-sodium citrate > Tripotassium citrate

Citric acid and its salts admixture										
(%)	(Citric Tri-sodium Tri-potassium acid citrate citrate		Tri-l ci	Tri-lithium citrate					
Admixture	(ml)	(%)water	(ml) (%)water	(ml) (%) water	(ml) (%)water		
	Water	Reduce	Water	Reduce	Water	Reduce	Water	Reduce		
0%	100	0	100	0	100	0	100	0		
0.025%	98	2	99	1	99	1	98	2		
0.050%	97	3	98	2	98	2	97	3		
0.075%	96	4	98	2	97	3	96	4		
0.100%	95	5	97	3	96	4	95	5		
0.125%	95	5	96	4	96	4	94	6		
0.150%	94	6	96	4	95	5	93	8		
0.175%	93	8	95	5	95	5	93	8		
0.200%	92	9	95	5	94	6	92	9		
0.225%	92	9	94	6	94	6	91	10		
0.250%	91	10	93	8	93	8	90	11		
0.275%	90	11	92	9	93	8	89	12		
0.300%	89	12	91	10	92	9	89	12		
0.325%	88	14	90	11	92	9	89	12		
0.350%	87	15	89	12	91	10	88	14		
0.375%	86	16	88	14	90	11	88	14		
0.400%	86	16	88	14	89	12	87	15		

Table 7: The water demand to get standard consistency

The initial and final setting time of cement mortars containing various dosages of citric acid admixture are shown in (Figure 1) and (Table 8). The results show extension of the initial setting time in the concentration below 0.375% and a shortening of the process in higher concentration. This clearly indicates that the citric acid can act as a retarder or accelerator in the setting process of Portland cement depending on the dosages we use.

The relationship between initial and final setting times and the properties of tri-lithium, tri-sodium and tri-potassium citrate are shown in Figure 2, 3 and 4 respectively. The effect of these admixtures is clearly indicate that they cause extension of the initial and final setting times at concentrations below 0.175 % and 0.20% for the tri-potassium and tri-lithium citrate respectively, while they shortened the process at higher concentrations, the results shown in (Table 8). It seems that the addition of tri-sodium citrate raised up the initial and final setting times at concentrations below 0.275% and 0.30% and reduced both processes at higher concentrations, respectively, as shown in (Table 8).

Generally, the above results implied that these admixtures in low dosages could behave as retarder, while in higher dosages they might be regarded as accelerators, that is related to the

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formation of ettringite crystals. However, with the absence of the citrate admixtures, the ettringite crystal can be formed within a few hours and enlarged in approximately 1 day after mixing. Because ettringite has a high-water content of 46% by weight, its formation affects the consistency and workability of cement while the early hydration of C3A+ CSH may be accelerated [30-31].

Table 8: Effect of admixtures on setti
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	Percentage change in the setting time when adding different ratios of admixtures $\%$							
%	% Citric acid		Tri-sc citr	Tri-sodium citrate		assium rate	Tri-lithium citrate	
	Initial setting time	Final setting time	Initial setting time	Final setting time	Initial setting time	Final setting time	Initial setting time	Final setting time
0	0	0	0	0	0	0	0	0
0.025	11.43	34.09	8.82	17.78	14.71	13.04	27.27	31.91
0.050	42.86	40.91	26.47	26.67	38.24	19.57	63.64	44.68
0.075	45.71	43.18	26.47	40	47.06	30.43	87.88	53.19
0.100	57.14	75	29.41	44.44	55.88	34.78	118.18	74.47
0.125	82.86	95.45	38.24	48.89	76.47	36.96	112.12	70.21
0.150	85.71	104.55	82.35	84.44	70.59	41.3	106.06	65.96
0.175	77.14	100	76.47	75.56	-5.88	-8.7	33.33	8.51
0.200	48.57	90.91	58.82	64.44	-35.29	-10.87	-21.21	-23.4
0.225	40	86.36	17.65	24.44	-47.06	-17.39	-45.45	-40.43
0.250	34.29	81.82	8.82	20	-55.88	-56.52	-57.58	-57.45
0.275	31.43	79.55	-23.53	13.33	-64.71	-58.7	-60.61	-65.96
0.300	25.71	75	-32.35	-11.11	-67.65	-60.87	-63.64	-65.96
0.325	14.29	59.09	-35.29	-26.67	-76.47	-65.22	-66.67	-68.09
0.350	2.86	18.18	-41.18	-28.89	-79.41	-69.57	-66.67	-70.21
0.375	-2.86	6.82	-47.06	-35.56	-82.35	-71.74	-69.7	-72.34
0.400	-5.71	9.09	-55.88	-55.56	-82.35	-78.26	-75.76	-76.6

Table 9 shows that all the admixtures in this study have the ability to reduce the quantity of absorbed water by cement in 28 days. Thus, this experiment was carried out by drying samples of cement containing the citrate salts at > 100 °C for 24 hrs, followed by immersing them in water for 24 hrs. This process included a blank sample for comparison.

Compo	Ratio % of the sample absorption after				
Additives	Cement (g)	Sand (g)	Water (g)	days	
Without admixture	185	555	74	5.93	
Citric acid	185	555	74	5.6	
Tri sodium citrate	185	555	74	5.63	
Tri potassium citrate	185	555	74	5.75	
Tri lithium citrate	185	555	74	5.58	

















It seems that the tri lithium salt is the most capable species for this process, while the citric acid followed by the tri sodium then the tri potassium salt has less ability.

Effect of these additives as anti-corrosive compounds were studied according to test method ASTM C 876 [31]. Thus, a Cu/CuSO₄ half-cell of potential (-0.316 V) was used as a reference at 22.2°C/reaction (2), while the counter half-cell was Fe/Fe²⁺ of potential (+ 0.44 V)/reaction (3) [32]; with the following cell-formula:

$$Cu \longrightarrow Cu^2 + + 2e - \dots (2)$$

Fe \longrightarrow Fe² + 2e - \dots (3)

Cathode (reduction) $Cu^2+(aq) + 2e \rightarrow Cu(s) + 0.316 V$ Anode (oxidation) $Fe(s) \rightarrow Fe^{2+} + 2e + 0.44 V$ Cell reaction $Cu^{2+}(aq) + Fe(s) \rightarrow Cu(s) + Fe^{2+}(aq) E_{cell} = +0.770 V$

anode (oxidation) Fe(s)|Fe²⁺(aq) Cu²⁺| Cu(s) Cathod (reduction)

The interpretation of the potential per ASTM C 876-91 Standard, a threshold potential value of -350 mV was established. Lower values of potential suggested corrosion with 95% probability; if potentials are more positive than -200 mV, there is greater than 90 % probability that no reinforcement steel corrosion occurs, and for those potentials between -200 mV and -350 mV corrosion activity is uncertain [31].

The corrosion experimental results showed a huge variety of these additives ant-corrosive ability. Thus, the partially submerged samples in brine 4% NaCl solution gave the results shown in (Figures 5,6,7). Figure 5 shows how addition of 0.1 % of the admixtures would stop corrosion of the rebar steel for different periods of submergence. It seems that in sample containing no additives, the rebar was 90% corroded in four months, but those with citric acid and tri-salt delayed corrosion for a period more than eight months (< -350 mV), while the potassium and sodium had stopped corrosion for 8 and 7 months respectively.

Addition of 0.15% of sodium and potassium salts raised the corrosive-periods to eight and seven months respectively, while the citric acid and lithium showed low efficiency, approximately less than six months as shown in Figure 6. Figure 7 represents their anti-corrosive efficiency upon addition of 0.200%. Levels below the established voltage (-350mV) has been achieved by sodium citrate, potassium citrate, citric acid and lithium citrate within 6 to 7 months successively.

CONCLUSION

Addition of citric acid and its salts admixture to ordinary Portland cement (OPC) at low dosage led to incrassating in ultimate compressive strength and lengthen the initial and final setting-time. However, at high dosage, decreasing of compressive strength and shortening of setting-time were observed. The presence of these admixtures in OPC, also causes decreasing in water demand as the dosage increased till achievement of normal consistency.





Figure 6. Effect of the admixture on the rebar corrosion using OPC Cement.



Figure 7. Effect of 0.200% of the admixture on the rebar corrosion using OPC Cement.

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DISCLOSURE

The authors declare no conflicts of interest.

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About the Corresponding Author

Dr. Zaki N. Kadhim

Summary of background:

Dr. Zaki N. Kadhim is a professor in the Department of Chemistry in the College of Science at the University of Basrah, Iraq. His main job includes lecturing for undergraduate and post graduate students in the field of inorganic chemistry. In addition, he is supervising 11 PhD candidates and master's in science students.

Current research focus:

- Metal containing polymer
- Schiff bases metal complexes
- Hydroxyapatite modification
- Drug delivery systems

Websites:

Facebook - https://www.facebook.com/zaki.alsokanee Researchgate - https://www.researchgate.net/profile/Zaki_Naser_Kadhim LinkedIn - https://www.linkedin.com/in/zaki-naser-75a36b107/

Permanent e-mail address:

zekinasser99@yahoo.com zaki.kadhim@uobasrah.edu.iq

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