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Effectiveness of different parameters on the efficiency of Electrochemical Chloride Extraction process

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الملخص العربى :

يعتبر صدأ الحديد من الإسباب الرئيسية المتسببة فى تدهور الخرسانه المسلحة ويرجع سبب هذا الصدأ لوجود أيونات الكلوريدات التى تعتبر من أهم الأسباب لحدوثه فى الخرسانه المسلحة، ويوجد العديد من الطرق التى تستخدم فى إزالة أيونات الكلوريدات من الخرسانه، ومن هذه الطرق الطريقه الإلكتروكميائيه وهى أكثر الطرق فاعليه وتوصى بها الأبحاث المختلفه.

الفكرة الرئيسيه لهذه الطريقه هى مرور تيار كهربى لمدة قصيرة بين حديد التسليح (كاثود) والأنود الخارجى الذى يوجد فى محلول قلوى موصل للكهرباء لإزالة أيونات الكلوريدات السالبه الموجوده على حديد التسليح لتذهب إلى الأنود الخارجى مما يقلل من فرص زيادة الصدأ وكذلك ايونات الهيدروكسيد المتسببه فى زيادة قلوية الخرسانه.

ABSTRACT;

Electro-chemical Chloride Extraction (ECE) is considered one of the most effective techniques used to extract chloride ions from reinforced concrete structures. The effectiveness of using ECE depends on some important factors such as anode type, current intensity, extraction duration, type of rebar, and chemical properties of concrete. On the other hand, ECE may cause some detrimental effects on some mechanical properties of concrete and steel such as a reduction in bond and compressive strengths of concrete, and embrittlement (i.e. .reduction in ductility) ductility of reinforcing steel

The major aim of this research work was to investigate the effect of the following important variables on the efficiency of ECE: Spacing between reinforcing bars Cathode type (internal cathode and external cathode) - Distance between anode and cathode - Number of reinforcing steel meshes inside the concrete - Location measured from the anode. The slab behavior before and after ECE was studied by determining compressive strength, concrete chloride content, and steel corrosion potential. The effect of initial chloride content on chloride extraction efficiency was investigated. Seven RC slabs were used in the experimental program

to investigate the effect of these variables on the efficiency of ECE with Chlorides (NaCl) concentration of 0.35% by weight of concrete.
Keywords: ECE; Chloride ions; Conductive cement paste; Corrosion;

1.INTRODUCTION

Durability is the main challenge that faces the field of steel reinforced concrete construction. Service life of concrete structures is dependent on durability aspects. Hence, durability unleashes service life, as well as saves cost repair processes. Corrosion of steel reinforcement is one of the crucial problems that the main problem of steel reinforced concrete Corrosion is the main problem we face which has a serious effect on steel reinforcement and therefore has a bad impact on concrete life time [1,2]. The main cause of steel corrosion is carbonation which causes a neutralization of all the alkaline elements in the cement because of the huge drop in pH in concrete [3]. This causes an extreme spreading for corrosion in steel reinforcement [4]. Leading to a continues regression in reinforced concrete properties [5–7]. Concrete always has a chloride; this chloride could be from many sources either external sources or internal sources. For internal source may be coming from the ingredient of concrete mix such as: aggregates or fine material, for external could be caused by the outside environment surrounding the construction such as: sea salt spray or direct sea water wetting. Many researches were made due to the need to improve the durability of reinforced concrete [8–17] or to repair a damaged one. There are many different ways to rehabilitate the concrete witch has a high chloride content such as: electrochemical chloride removal , electrochemical injection of organic corrosion inhibitor .There are also different rehabilitation methods such as: cathodic protection (CP), corrosion inhibitors (e.g. calcium nitrate), and the usual repair method when repair a patch to avoid the corrosion effect on steel reinforcement of concrete. In this study we used ECE to rehabilitate the concrete from chloride content with electric current of 3mA/ m2 and duration of 6 weeks.

2.MTERIAL, TEST SPECIMENS, METHODOLOGY AND EXPERIMENTAL PROCEDURE.

2.1.Material and test specimens:

In the current study, the used material for concrete production comprises: ordinary Portland cement (type I – CEM I 42.5N) conforming to ASTM C150 ,natural sand of specific gravity (2,67), crushed stone of max nominal size 10 mm and specific gravity (2.703) and tab water. Sodium chloride salt of concentration 0.35% by weight of concrete to provide source of Cl- ions. Specimens were reinforced by 12 mm steel bars of yield strength 480 MPa and tensile strength 595 MPa. Layer of protective cement paste containing un-galvanized steel mesh see

Fig.1 was used as an anode for ECE process. Table 1. displays mix proportions for produced concrete and cement paste and the resulted compressive strength.

Fig. 1. protective cement paste containing un-galvanized steel mesh

2.2.Methodology:

Seven specimens of dimensions 650 × 650 mm and variable thicknesses were prepared to investigate the effect of the parameters under consideration on the performance of ECE process. These parameters comprise the following: (1) spacing between reinforcing rebars, (2) thickness of concrete element (distance between external anode and external cathode), (3) Types of cathodes (internal cathode / external cathode, (4) Number of steels meshes and (5) Distance (location) measured from concrete surface (anode side). Four specimens of thicknesses 120 mm were reinforced by using lower steel mesh of diverse spacing 50 mm, 100 mm, 200 mm and 200 mm. Two specimens of thicknesses 180 mm and 240 mm were reinforced by using lower steel mesh of spacing 200 mm. One specimen of thickness 180 mm was reinforced by using lower and upper steel meshes of spacing 200 mm. Test matrix is shown in Table 1 and Fig.2

Table 1: Test matrix.

Specimen	**Thickness (mm)**	**Spacing between steel bars (mm)**	**(Lower/upper) mesh**	**Type of cathode (Internal/external)**
12 / 5 / Int	120	50	Lower	Internal
12 / 10 / Int	120	100	Lower	Internal
12 / 20 / Int	120	200	Lower	Internal
12 / 20 / Ext	120	200	Lower	External
18 / 20 / Ext	180	200	Lower	External
24 / 20 / Ext	240	200	Lower	External
18/ 20 / Ext (2msh)	180	200	Lower & upper	External

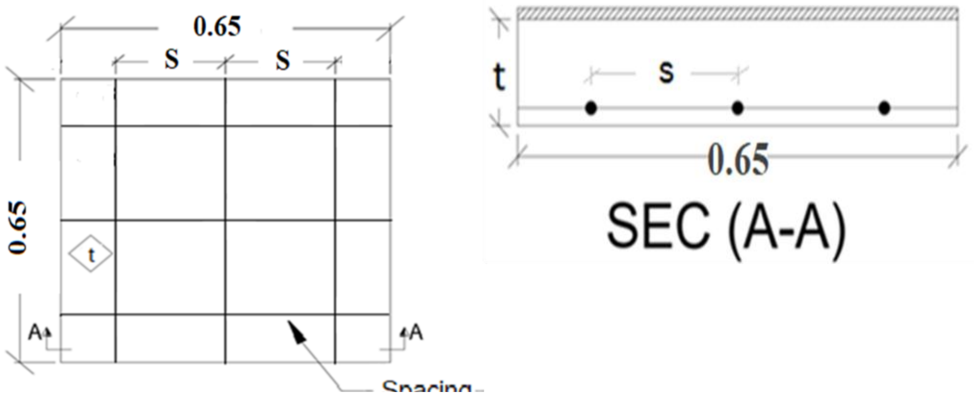
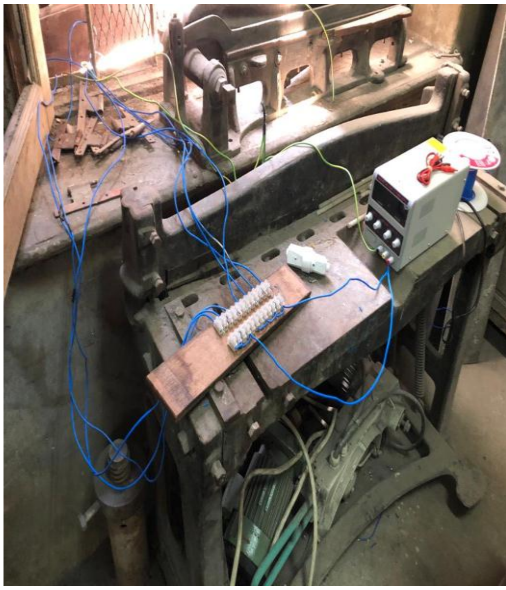


Fig. 2. Slab specimens

2.3.Experimental procedure:

Steel bars were fabricated with the aforementioned configurations and placed into wood molds with dimensions as mentioned before. Specimens were demolded 24 hours after concrete casting. Afterwards, they were cured by using wet burlap for 28 days .

ECE process was conducted on the seven specimens in the following sequence: (1) un-galvanized steel mesh was put on each specimen to be used as anode, (2) protective cement paste was poured on the specimen to protect the anode (un-galvanized steel mesh) from deterioration due to direct contact with water, (3) electric current of intensity 3mA/m² was applied by using DC power supply for six weeks as recommended by Nourhan Elsayed et al [18] See Fig3&4. For specimens (12 / 5 / Int), (12 / 10 / Int) and (12 / 5 / Int), steel reinforcement work as cathode and the un-galvanized steel mesh work as anode. While, another layer of cement paste containing un-galvanized steel mesh was applied on the other side for the rest to work as external cathode.



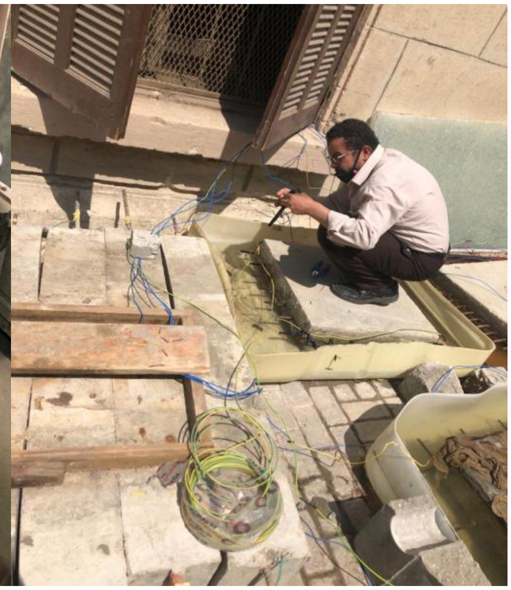


Fig. 3. Fig. 3. DC power supply **Fig. 4. Connection between DC and the slabs**

At the end of ECE process duration, two core specimens of diameter 70 mm were extracted from different positions of each specimen in the direction of specimen depth. Full length core specimens were extracted. Afterwards, core specimens were saw cut into pieces of equal length 30 mm as shown in Fig.5 chemical analysis tests were conducted on the aforementioned pieces to obtain the chloride concentration profile along the depth of specimens.

3. RESULTS AND DISCUSSION

Internal and external cathode ECE processes were applied on seven specimens for six weeks. Afterwards, two core specimens were extracted from each specimen and saw cut to pieces with equal length of 30 mm. These pieces were tested to obtain the chloride concentration profile along the depth of each specimen. Test results are displayed in

Table 2 and Fig.5

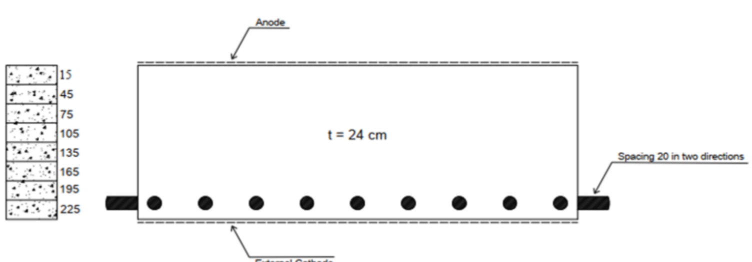


Fig. 5. Core profile

Table 2: Test results.

Specimen	Location (mm)	% Cl^- (%)*			
		Core1	Core2	Average	
12 / 5 / Int	15	0.1029	0.113	0.10795	0.2
	45	0.1953	0.1953	0.1953	
	75	0.213	0.2201	0.21655	
	105	0.2414	0.3195	0.28045	
12 / 10 / Int	15	0.075	0.1065	0.09075	0.164
	45	0.1597	0.1775	0.1686	
	75	0.1598	0.213	0.1864	
	105	0.213	-	0.213	
12 / 20 / Int	15	0.1043	0.08165	0.092975	0.149
	45	0.1392	0.1204	0.1298	
	75	0.1704	0.171	0.1707	
	105	0.213	0.1953	0.20415	
12 / 20 / Ext	15	0.1065	0.142	0.12425	0.167
	45	0.1775	0.1882	0.18285	
	75	0.1739	0.1775	0.1757	
	105	0.1836	0.1898	0.1867	
18 / 20 / Ext	15	0.1526	0.1753	0.16395	0.197
	45	0.2024	0.1989	0.20065	
	75	0.1975	0.1875	0.1925	
	105	0.2059	0.1953	0.2006	
	135	0.2146	0.1975	0.20605	
	165	0.2201	0.2188	0.21945	
24 / 20 / Ext	15	0.142	0.1775	0.15975	0.221

	45	0.1953	0.226	0.21065	
	75	0.2263	0.2405	0.2334	
	105	0.2382	0.2453	0.24175	
	135	0.223	0.223	0.223	
	165	0.2472	0.213	0.2301	
	195	0.253	0.2508	0.2519	
	225	-	-	-	
18/ 20 / Ext (2msh)	15	0.1897	0.213	0.20135	0.229
	45	0.243	0.223	0.233	
	75	0.2437	0.2253	0.2345	
	105	0.243	0.2175	0.23025	
	135	0.2275	0.2275	0.2275	
	165	0.2682	0.2339	0.25105	

*** Percentage of chlorides by weight of concrete.**

3.1Effect of spacing between steel bars:

Application of the ECE process on the specimens (12/5/int), (12/10/int) and (12/20/int) Chloride concentration was 0.2%, 0.164% and 0.149% (as shown in Figure.6) which represent about 57%, 47% and 42% respectively from the original chlorides in concrete before ECE (0.35% by weight). This means that the reduction in chloride concentration for specimens are about 43%, 53% and 58% respectively

These observations can be explained by that the enlargement on spacing between steel bars improves the uniformity of field around them.

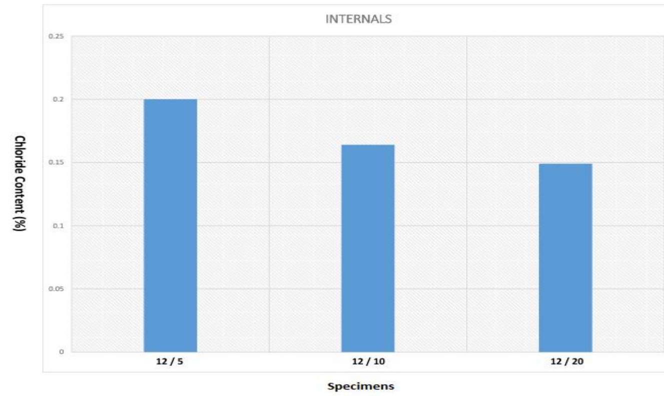


Fig. 6. Slab spacing between steel bars results

3.2 Effect of Thickness of RC slabs (distance between external anode and external cathode):

Application of the ECE process on the specimens (12/20/Ext), (18/20/ Ext) and (24/20/ Ext) Chloride concentration for slab thickness respectively is 0.167%, 0.197% and 0.221% (as shown in Figure. 7) which represent about 48%, 56% and 63% respectively from the original chlorides in concrete before ECE (0.35% by weight). This means that the reduction in chloride concentration for specimens are about 52%, 44% and 36% respectively. It can be easily attributed to a stronger attractive force done by the anode (with +ve charge) to the chloride ions (with –ve charge) for the smaller thickness rather than the bigger one.

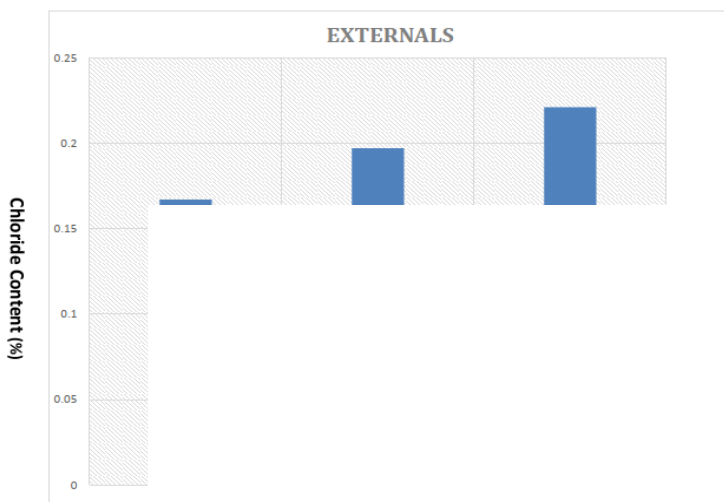


Fig. 7. Thickness of RC slabs results

3.3 Effect of cathode type:

Two types of cathodes were considered in the experimental program, internal cathode (steel bars) and external cathode (un-galvanized steel mesh in conductive cement paste on the surface). Chloride concentration for internal and external cathodes are 0.149%, 0.167% (as shown in Figure.8) which represent about 42% and 48% respectively from the original chlorides in concrete before ECE (0.35% by weight). This means that the reduction in chloride .concentration for specimens are about 58% and 52% respectively

Internal cathode showed a slight better performance of ECE than the external cathode. These results can be attributed to that the distance between cathode and anode for specimen (12/20/int) is lower than that of specimen (12/20/ext).

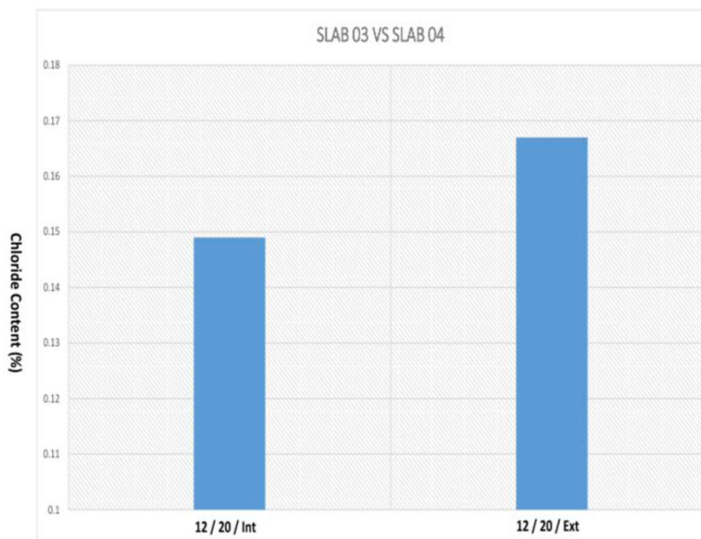


Fig. 8. Types of cathodes results

3.4 Effect of number of steels meshes:

Regarding the effect of upper and lower steel meshes (two meshes), the specimens (18/20/ext) and (18/20/ext/2meshes) were investigated. Chloride concentration for one and two meshes are 0.197%, 0.229% (as shown in Figure .9) which represent about 56% and 65% respectively from the original chlorides in concrete before ECE (0.35% by weight). This means that the reduction in chloride concentration for specimens are about

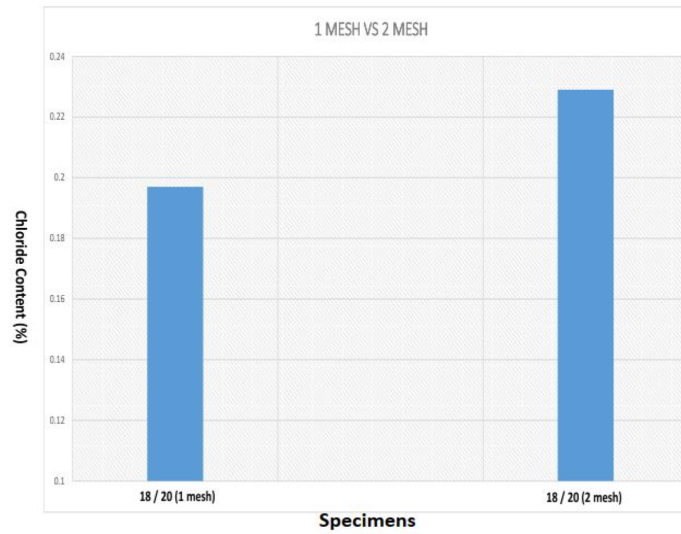


Fig. 9. Number of steels meshes results

3.5 Effect Location measured from the external anode:

Average chloride content values were obtained for various positions at certain intervals from the external anode as mentioned before. Results demonstrate improvement of the performance of ECE at the positions close to external anode. (i.e. the positions closer to the anode have a lower chloride content compared to the positions far from the anode) This can be attributed to that the positions located closer to the anode, the more strong the attraction forces applied by the anode and consequently more reduction in the chlorides content**.**

4. CONCLUSIONS

Based on the obtained test results and the analysis and discussion of these results, the following points can be easily concluded:

1- The reduction in chloride concentration for specimens (12/5/int), (12/10/int) and (12/20/int) is 43%, 53% and 58% respectively. due to a more uniform field around the steel bars.
2- The reduction in chloride concentration for specimens (12/20/Ext), (18/20/ Ext) and (24/20/ Ext) is 52%, 44% and 36% respectively . This can be easily attributed to a more stronger attraction force done by the anode (with +ve charge) to the chloride ions (with –ve charge) for the smaller thickness rather than the bigger one.
3- The reduction in chloride concentration for specimens , internal cathode (steel bars)

and external cathode (un-galvanized steel mesh) are 58% and 52% respectively. The smaller the distance between anode and cathode, the higher the anode attractive forces.

4- The reduction in chloride concentration for specimens (18/20/ext) and (18/20/ext/2meshes) are 44% and 35% respectively. One mesh showed a better performance of ECE than the case of two meshes. This result can be attributed to that the presence of upper reinforcement mesh in addition to the lower reinforcement mesh restricted the process of chloride extraction.

5- The effectiveness of ECE is depend on the position of each point measured from the external anode All positions located close to the anode have a lower chloride content compared to the points far from the anode.

5. Recommendation:

It is recommended to investigate the effect of the following parameters on the efficiency of ECE:

- New anode materials having higher electrical conductivity.

-Efficiency of ECE for the case of geo-polymer concrete due to its wide spread applications.

- Smart systems for ECE which operate automatically if the percentage of chlorides exceed a certain limit and shut down automatically if this percentage decreased.

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