Using the Fly Ash to Reduce the Steel Corrosion in Lightweight Concrete

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Abstract

The aim goal of this research was to study the effect of using the fly ash to reduce the steel corrosion in lightweight concrete. The test which adopted was compressive strength test, Rapid chloride permeability test and electrochemical parameters test. In the compressive strength test found that adding the fly ash to concrete with change the water-cement ratio to product the same value of workability this addition lead to reduce the compressive strength test with increased the fly ash ratio, the compressive strength value was (31MPa to 44 MPa) and this value is above the (30 MPA) which recommended to use it in construction. In the Rapid chloride permeability test found with increasing the fly ash ratio the permeability became lower. In the electrochemical parameters test found that increasing the fly ash ratio lead to increase the parameters which increased the steel protection from the corrosion in lightweight concrete.

Keywords: Lightweight concrete, fly ash, compressive strength test, Rapid chloride permeability test and electrochemical parameters test.

1. Introduction

The main goal of this research is to increase the resistance of steel reinforcement to the corrosion by using the Fly ash (class F). Class F fly ash significantly increases the ability of concrete to resist attack from sulfates in soil or ground water. Additionally, Class F fly ash has been proven through extensive research and field experience to be highly effective in mitigating the deleterious effects of expansive alkali-silica reactions (ASR) in concrete. It is produced from the combustion of pulverized bituminous or Texas lignite coal. When correctly proportioned, concrete which contains fly ash can have equivalent or greater 28-day compressive strengths when compared to plain Portland cement concrete. Due to the pozzolanic reaction fly ash concrete will continue to gain strength beyond 28 days exceeding that of plain Portland cement concrete, Rajamane N P *et al.*, 2003.

Class F fly ash can be used as a pozzolan in virtually any concrete application. When correctly proportioned Class F fly ash will add many benefits such as increased strength, increased durability and reduced permeability. Class F fly ash is particularly beneficial in high performance concrete applications where high compressive strengths are required or where severe exposure conditions demand highly durable concrete. Class F fly ash is also very effective at mitigating problems associated with alkali-silica reactions. In mass concrete placements where low heats of hydration are required class F fly ash is very advantageous in controlling temperature rise. It has been widely used as a supplementary cementing material in conventional concretes of normal weight, Dattatreya, [5]. However, use of Fly ash as a source material for production of coarse aggregate is very attractive, since coarse aggregate in a concrete occupies a major portion of its volume. Powdery granules of Fly ash can be agglomerated minerologically by sintering and then used as CA, Rajamane (2003).

2. Materials

2.1 Cement

Portland cement 43 grade was used in this study, the properties of cement was presented in table 2.

Table 1: Chemical composition of cement

Compounds	% (by weight)	Limit of Iraqi specification No. 5/1984
Lime	64.43	-
Silica	21.14	-
Alumina	5.78	-
Iron oxide	3.59	-
Sulfite	2.35	< 2.8%
Magnesia	1.52	< 5%
Loss of ignition	0.89	< 4%
Lime saturation factor	0.92	0.66 – 1.02
Insoluble residue	0.34	< 1.5

Table 2: properties of cement

Properties	Limit	Limit of Iraqi specification No.5/1984
Fineness (m^2/kg)	285.0	230 (min)
Initial setting time (min)	3:20	0:45 (min)
Final setting time (h)	4:15	10:0 (max)
Soundness	0.19	0.8 (max)
3 days age compressive strength (Mpa)	24.96	15 (min)
7 days age compressive strength (Mpa)	45.00	23 (min)

2.2 Steel

High yield strength cold twisted deformed bar of Fe 415 graded conforming to Is 1786 has been used.

2.3 Fly ash

Fly ash class F was used in this study, the properties of fly ash was presented in table 3.

Table 3: Properties of fly ash

Property	Fly ash
Type	Class F
Conforming Code	IS:3812
Specific gravity	2.2
Fineness (Blaine) m^2/kg	310
Cementing efficiency, k	0.8 @ 28 day
Bulk density kg/m^3	995

Table 4: Properties of Sintered Fly ash aggregates ($SFAA_g$)

Property	Value
Sized produced mm	1 to 20
Shape	Almost spherical
Angularity number' (AN) (For spheres, Voids content=26%, AN=0	5 for 10 mm
Specific gravity of grains of $SI:AA_S$	1.707
Saturated water absorption	21.5
Oven dry condition Apparent specific gravity	1.287
Air dry condition Apparent specific gravity	1.289
Saturated Surface Apparent specific gravity	1.564
Loose bulk density, kg/m^3	820.1

2.4 Fine aggregate

Natural sand of desert origin was used in this study with Specific gravity of 2.81, Fineness modulus of 2.81 and Bulk density kg/m^3 of 1628, the properties of gradation of the sand aggregate was presented in table 5.

Table 5: Properties of sand

No. Sieves	Percentage of Passing	Limit of Iraqi specification No. 45/1984
No.4	97	90-100
No.8	87	85-100
No.16	79	75-100
No.30	65	60-79
No.50	22	12-40
No.100	3	0-10
The ratio of salt So_3 %	0.482	≤ 0.5

2.5 Coarse aggregate

Natural crushed stone aggregate was used in this study with Specific gravity of 2.89, Fineness modulus of 6.5 and Bulk density kg/m^3 of 1720, the properties of gradation of the coarse aggregate was presented in table 6.

Table 6: Properties of gradation of the coarse aggregate

No. Sieves	Percentage of Passing	Limit of Iraqi specification No. 45/1984
1.5”	100	100
3/4”	98	95-100
3/8”	46	30-60
N0.4	3	0-10
The ratio of salt So_3 %	0.085	≤ 0.1

3. Experimental Work

3.1 Mix Proportions

A LWC with SFAA$_S$ (satisfying the requirements of ASTM C 330) as Coarse aggregates and having weight proportions of cement: sand aggregate: coarse aggregate at 1:1:2 was evolved with adequate workability LWC. The cement content of LWC was replaced by 25% and 50% FA to obtain two more LWC mixes, LWCF25 and LWCF50, respectively. Water-to-cement ratios of the mixes were adjusted to achieve similar levels of workability.

Table 7: Mix proportions

Mix ID	LWCO	LWCF25	LWC F50
Type of fine aggregate	desert origin		
Water-to-cement ratio	0.30	0.32	0.42
(cement+FA): Sand: Course aggr. (weight)	1:1:2	1:1:2	1:1:2
Superplaticiser (CAE based) (%)	0.02	0.1	0.05
Workability, slump (mm)	100	150	125

3.2 Specimen Testing

Thirty six cubes of concrete of (150x150) mm size were molded for tests of compressive strength. For corrosion resistances of these mixes were investigated, nine cylinders of concrete (100mm diameter, 50mm thick) were molded for tests of Rapid Chloride Permeability Test (RCPT) of ASTM C 1202. Eighteen slab (50x300x300) mm were cast for testing the Electro chemical parameters with a central 20mm Ms rod. A laboratory ribbon type horizontal mixer was used. The mixes were cohesive and could be easily compacted in steel moulds using a table vibrator. Steel moulds were used to cast cube and cylindrical specimens, and wooden mould for slab specimens. The test specimens could be demoulded easily after 24 hours of casting and they were submerged in water for effecting curing process.

3.3 The Testing of Concrete Mixes

The most common concrete tests carried out in this study are the Compressive Test, Rapid Chloride Permeability Test (RCPT) and Electro Chemical Parameters Test (ECPs).

3.3.1 The Compressive Strength Test

The Compressive Strength Test measures the compressive force a concrete sample is able to withstand. A concrete sample (cube), a compressive test machine hydraulic test machine (MATEST) is shown in Fig. (1) Was used to complete this test, this test was done by the structural lab in the Engineering collage at Thi-Qar University.. The thirty six cubes with (0%, 25%, and 50%) ratio of Fly ash, four cubes for each ratio and for each curing periods 3, 7 and 28 days used for this test are all having dimension of 150mm x 150mm. After the sample is cured, it is placed between two metal plates in the compressive test machine. The machine applies force increasing at a constant rate upon the sample. When the sample fails, the compressive strength is recorded.

Figure (1): Hydraulic Test Machine (MATEST)

3.3.2 Rapid Chloride Permeability Test (RCPT)

In the ASTM C1202 test, a water-saturated, 50-mm thick, 100-mm diameter concrete specimen is subjected to a 60 V applied DC voltage for 6 hours using the apparatus shown in Figure 2. In one reservoir is a 3.0 % NaCl solution. The total charge passed is determined and this is used to rate the concrete according to the criteria included in Table 8. This test, originally developed by Whiting [1981], is commonly (though inaccurately) referred to as the "Rapid Chloride Permeability Test" (RCPT). This name is inaccurate as it is not the permeability that is being measured but ionic movement. In addition, the movement of all ions, not just chloride ions, affects the test result (the total charge passed). There have been a number of criticisms of this technique.

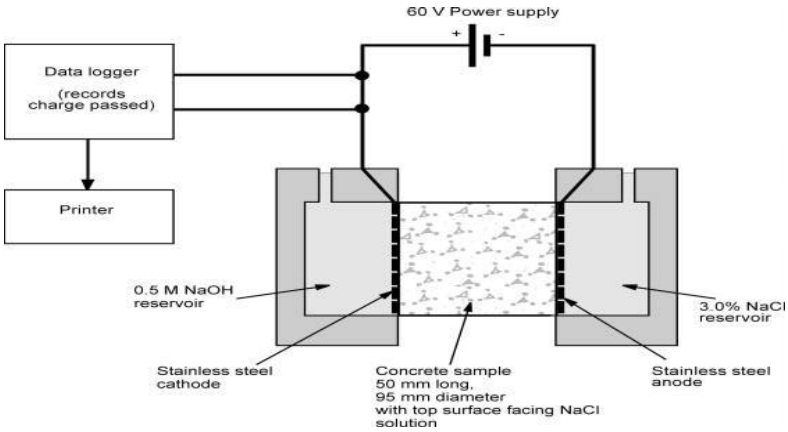


Figure 2: (ASTM C1202) test setup. "Rapid Chloride Permeability Test"

Lower quality concretes heat more as the temperature rise is related to the product of the current and the voltage. The lower the quality of concrete, the greater the current at a given voltage and thus the greater heat energy produced. This heating leads to a further increase in the charge passed.

Table 8: RCPT ratings (per ASTM C1202)

Charge Passed (coulombs)	Chloride Ion Penetrability
> 4,000	High
2,000-4,000	Moderate
1,000-2,000	Low
100-1,000	Very Low
< 100	Negligible

3.3.3 Electro Chemical Parameters Test

The 'electrochemical parameters' (ECPs) of the 28 days eighteen cured slab specimens (300*300*50mm) were determined using an equipment known as GECOR which utilizes electrochemical polarization resistance technique. The measurements were made after exposure to 3.0 % NaCl solution. Using the classification of corrosion rate corresponding to concrete resistivity, given by Tay Woodraw Research Laboratory of UK (1980) (Table 9), it is seen that the corrosion rate status changes was from 'high' to 'very high' for LWC without FA and in LWCs with FA, the corrosion rate remained at 'very low'. Similar observation can be made based on the corrosion rate classification by Andrade and Alonse (2001) (Table 10). This can be attributed to the lower chloride permeability of FA based cement matrix as observed in RCPT.

Table 9: Electrical resistivity of concrete and corrosion rate (Tay Woodrow Research Lab. UK) (1980)

Concrete resistivity	Corrosion rate	Type of LWC_S
<5 kilo-ohm-cm	Very high	LWC0
5-10 kilo-ohm-cm	High	
10-20 kilo-ohm-cm	Low	LWCF25 and LWCF50
>20 kilo-ohm-cm	Negligible	

Table 10: Corrosion rate of steel in concrete (Andrade & Alonso) (2001)

Corrosion rate of steel in concrete	Corrosion rate	Type of LWC_S
<0.1 $\mu A/cm^2$	Negligible	LWCF50
0.1 to 0.5 $\mu A/cm^2$	Low	LWCF25
0.5 to 1 $\mu A/cm^2$	Moderate	
>1 $\mu A/cm^2$	High	LWC0

4. Results and discussion

The performance of the fly ash which added to the light weight concrete was evaluated by determining the Compressive Strengths, Rapid Chloride Permeability and Electro Chemical Parameters of the concrete specimens cast with the fly ash class F.

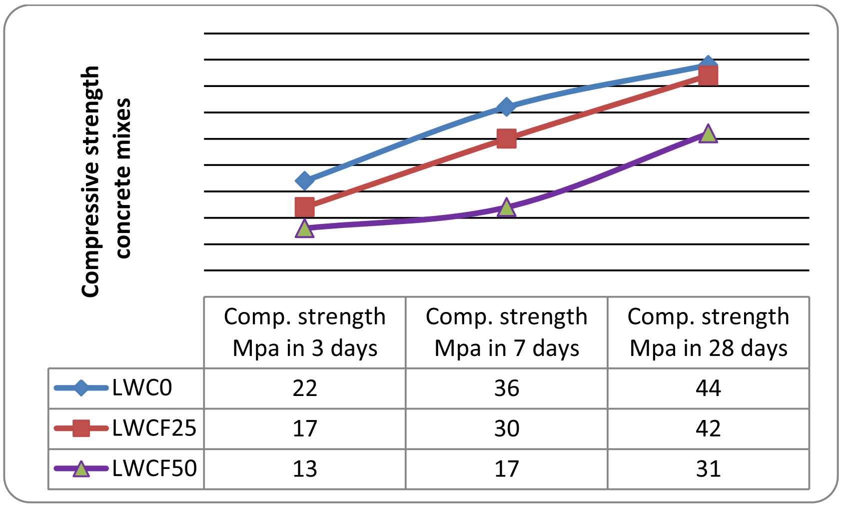
4.1 Testing of Compressive Strength

The results of the compressive strength tests show that the compressive strengths of the specimens reduce the compressive strength test with increased the fly ash ratio, the compressive strength value was (31MPa to 44MPa) and this value is above the (30MPA) which recommended to use it in construction.

Table 11: Compressive strength concrete mixes

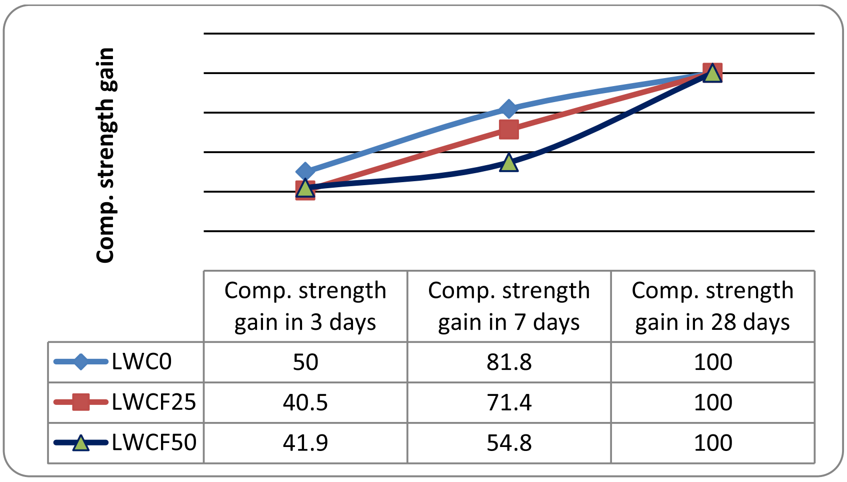
No	compressive strength MPa for the LWC0	compressive strength MPa for the LWCF25	compressive strength MPa for the LWCF50	curing periods
1	21.8	17.3	12.5	3 days
2	22.4	16.8	13.7	
3	20.9	15.8	13.1	
4	22.7	18.5	12.9	
Avg.	22.0	17.0	13.0	
1	35.8	30.2	16.5	7 days
2	34.9	30.5	17.4	
3	36.2	28.5	16.2	
4	37.3	31.1	17.9	

Avg.	36	30	17	
1	43.8	42.1	30.8	28 days
2	44.7	42.8	31.2	
3	43.5	41.2	30.5	
4	43.8	42.2	31.5	
Avg.	44	42	31	



	Comp. strength Mpa in 3 days	Comp. strength Mpa in 7 days	Comp. strength Mpa in 28 days
LWC0	22	36	44
LWCF25	17	30	42
LWCF50	13	17	31

Figure (3): Compressive strength concrete mixes



	Comp. strength gain in 3 days	Comp. strength gain in 7 days	Comp. strength gain in 28 days
LWC0	50	81.8	100
LWCF25	40.5	71.4	100
LWCF50	41.9	54.8	100

Figure (4): Compressive strength gain in concrete mixes with age

The 28 day compressive strengths of LWC mixes exceeded 30 MPa (Fig. 3). These concretes can be taken to be equivalent to M25 grade. As per IS: 456-2000, a minimum structural grade is M20 and hence, the LWC mixes of the present study have potential for use as structural material in concrete constructions. Addition of FA as partial 'cement replacement material' resulted in more gradual gain of strength (Fig. 4), due to the slower hydration reactions in cement-fly ash paste than in cement paste alone (Rajamane, 2003e; Joshi, 1999). It may be noted here that figs 3 and 4 refer to the strengths at different ages considering the 28 day strength as 100%. It is well known fact that after 28 days, fly ash based mixes would gain more strength. However, since most of the structural designs still tend to consider 28 day strength, this age was taken as basis for the calculating the rate of strength gain.

4.2 Rapid Chloride Permeability Test (RCPT)

In the present study, we used nine cylindrical specimens, LWC_S with (0, 25% and 50%) FA had 'moderate', 'low' and 'very low' degrees of chloride penetration resistances (Fig.5). The reduction in chloride permeability of LWC_S with FA may be attributed to the poor refinement because of pozzolanic reactions and fine filler action of fly ash which has been a well documented aspect of binder matrix containing FA, Rajamane, (2003), Malhotra (1994).

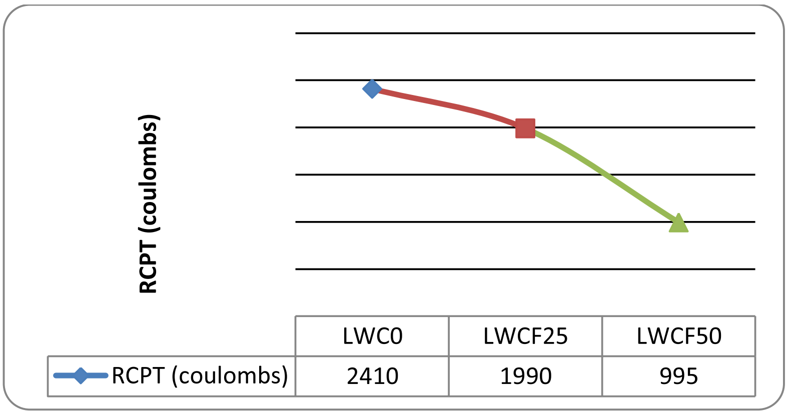


Figure (5): Chloride permeability of concrete mixes

4.3 Electro Chemical Parameters Test

In the present study, we used eighteen slab specimens. Initial test data on ECP_S, before the start of exposure to corrosive environment indicate the negligible levels of corrosion activity on the steel bar surface. After 100 days of exposure, the LWC with 50% FA had better resistance to corrosion than that with 25% FA. The actual corrosion rates measured by GCOR in LWC_S indicate the beneficial effects of FA in LWC_S due to reduction in pH of pore solution because of reaction of FA with calcium hydroxide of the hydrated cement, Rajamane (2003g), (2003h). It is to be noted here the half cell potential values at 28 days LWC_S are observed to be more negative than -350Mv, indicating a higher corrosion activity around the steel present inside the concrete matrix (Table 12). This could be due to either inadequacy of 28 days of curing period to develop denser matrix system, or the porous nature of LWC itself. However, potential measurements are generally taken as only indicative in nature and they cannot be taken as definite pointers to the actual status of corrosion always and this has been commonly seen noticed many authors, Ping *et al* (1997). In the present study, the relative values of half potential before and after accelerated corrosion test period are considered for understanding comparative durability of LWCS with and without FA.

Table 12: Electro - chemical potential of concrete and corrosion rate (ASTM C876)

Less negative than -200mV ($Cu/CuSo_4$)	90% probability of no corrosion
-200mV to -350mV	Increasing probability of corrosion
More negative than 350mV	90% probability of corrosion

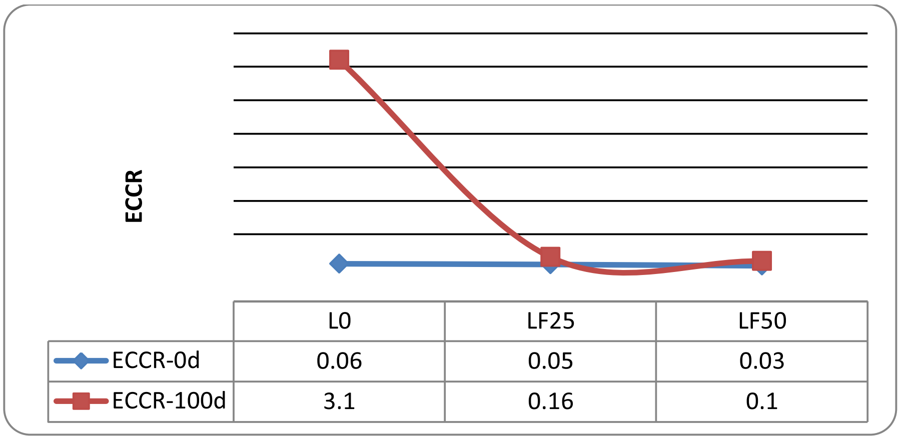


Figure (6): Electro-chemical corrosion rate

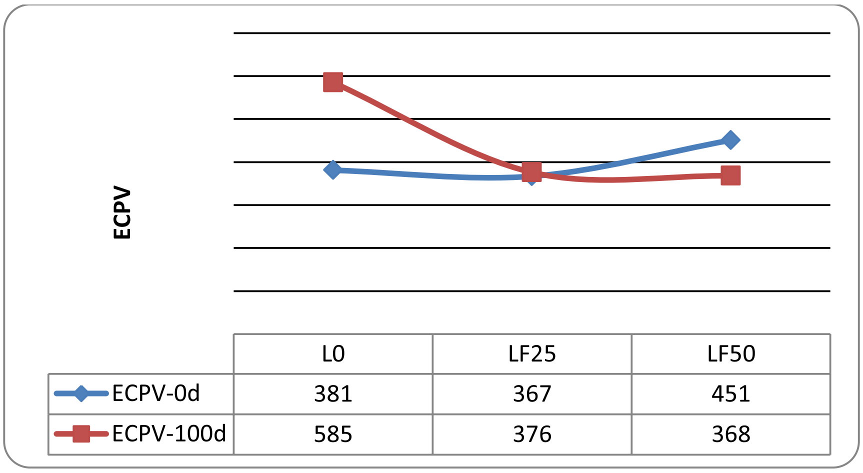


Figure (7): Electro-chemical voltage potential

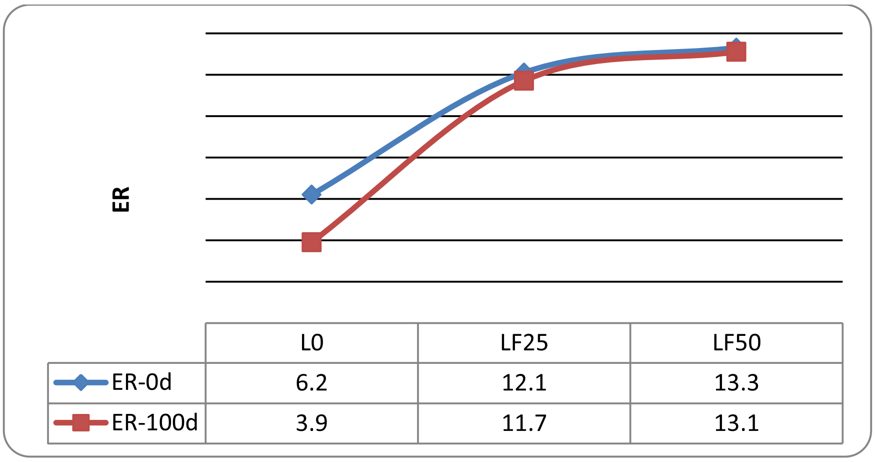


Figure (8): Electrical resistivity

5. Conclusion

The results of this investigation found that replacement of part of the cement by the Fly Ash to have the following effects:

1. Sintered fly ash aggregates ($SFAA_S$) can be used as coarse aggregates (CA_S) to achieve 28 days compressive strengths of 31 to 44 MPa in concretes which are ‘lightweight concretes’ (LWC_S).
2. LWC without fly as (FA) has moderate chloride permeability as per ASTM C1202. However, with 25% FA in LWC, this permeability becomes low, which further reduces to, very low at 50% FA. Thus, addition of FA to LWC is highly beneficial in this respect.
3. Accelerated corrosion exposure to sodium chloride solution indicates that LWC without FA offers adequate protection to steel embedded in concrete, as observed by satisfactory values of electrochemical parameters (ECPS) such as ‘electrochemical corrosion rate’ (ECCR), ‘electrochemical voltage potential’ (ECVP) and ‘ electrical resistivity’ (ER).
4. The study showed that the ‘light weight concretes’ can be produced by using ‘sintered fly ash aggregates’ as coarse aggregates. Durability of these concretes is enhanced significantly by use of fly ash as ‘cement replacement material’, particularly adopting the 50% FA content in binder of concrete.
5. Cement content of lightweight concrete (LWC) is generally more than the normal weight concrete (NWC) when measured by weight. This is due to lower density of lightweight aggregates (LWA_S). However, if the contents of LWC and NWC are considered on absolute volume basis, the difference in cement contents would not look quite contrasting. Moreover, due to porous nature of LWA_S, the water is held in LWC_S over longer period which reduces the drying shrinkage cracking possibility. Thus the

seemingly higher content of binder paste should not pose problems in LWC_S. One can note also that by using FA as ‘cement replacement material’ (CRM), the actual Portland content of concrete decreases which would reduce the heat of hydrated generated in the unit mass of concrete.

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7. Nomenclature

CAE	Computer aided engineering
CA_S	Coarse aggregates
CRM	Cement replacement material
ECP	Electrochemical parameters
ECCR	Electrochemical corrosion rate
ECVP	Electrochemical voltage potential
ER	Electrical resistivity
EC	Electric charge
FA	Fly ash
LWC	Light weight concrete
NWC	Normal weight concrete
RCPT	Rapid Chloride Permeability Test
SFAA	Sintered fly ash aggregate

أستعمال (الرماد الطائر) لتقليل تأكل حديد التسليح في الخرسانة الخفيفة الوزن

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الخلاصة

الهدف من هذا البحث هو دراسة أضافة الرماد الطائر الى الخرسانة الخفيف الوزن لتقليل التآكل في حديد التسليح حيث أظهرت نتائج الأختبارات التي أجريت وهي فحص مقاومة الأنضغاط وفحص النفاذية السريعة للكلورايد وفحص العوامل الكهروكيميائية للخرسانة الخفيف الوزن. حيث أظهر فحص مقاومة الأنضغاط أن أضافة الرماد الطائر ألى الخرسانة مع تغيير نسبة الماء إلى السمنت لجعل قابلية التشغيل ذات قيم متقاربة للخلطات بجميع النسب، أن هناك أنخفاض في مقاومة الأنضغاط كلما زادت نسبة الرماد الطائر ولكن القيم بقيت ضمن الحدود المطلوبة في المنشأت وهي أعلى أو تساوي (30MPA) حيث كانت القيم تتراوح بين (31MPa إلى 44MPa). في فحص النفاذية السريعة للكلورايد أظهرت التجارب أنه كلما أزدادت نسبة الرماد الطائر المضاف إلى الخرسانة قلت النفاذية. من فحص العوامل الكهروكيميائية وجد ان أضافة الرماد الطائر يزيد من معدل العوامل التي تزيد من حماية الحديد الموجود في الخرسانة ضد التآكل.