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Influence of Rebar Shaked - Cement Paste Ring on the Durability of Reinforced Concrete Structures

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Abstract **- The major cause of corrosion in R.C Structures is a porous zone at the interface of rebar and concrete which is due to poor compaction, high porosity and high bleeding at the Interfacial Transition Zone (ITZ) of reinforcement and Concrete. This paper introduces a new method of combating corrosion through construction technique-Rebar shaking. In this method, rebar is turned into a vibrator. Cement Paste Ring (CPR) is developed hence compaction is improved bleeding is eliminated and porosity is reduced at ITZ. This work initially establishes CPR optimal thickness, hence at ITZ, it determines bond between rebar and concrete through pull-out tests; the W/C ratio which is critical for controlling corrosion and PH level that form protective layer which protect steel from corrosion. The results of Pull-out tests, W/C ratio at CPR zone and PH level logically cohere thus the benefits of rebar shaking to combat corrosion is promising.**

Keywords: ***Rebar shaker; Cement Paste Ring; durability; corrosion; bond; curing***

1. INTRODUCTION

There is extensive evidence for the last two decades to showing that concrete structures all over the world are deteriorating at an unacceptable rapid rate. This poses greater challenges on ensuring long-term service life performance of concrete structures (Swamy, 2000, 2003, 2005 and Mays, 2003). To deal with these unwanted consequences of corrosion in RC structures, several methods (i.e., electrochemical techniques, coatings, steel-replacement technology, corrosion inhibitors) of corrosion control of steel-reinforced concrete have been invented. However, these methods of controlling corrosion are facing many challenges regarding their cost effectiveness, sustainability, environmental aspects as well as their effectiveness, acceptability and many other limitations (Chung, 2001). Furthermore, despite the existence of strict regulations and tight codes, but still the threat of corrosion is unacceptably high (Richardson, 2002).

The challenges of corrosion control methods are common in developed world; however these Corrosion Control methods are hardly adopted in developing countries due to the economic and technological levels. Core objective of these corrosion control methods is to improve bond or Interfacial Transition Zone (ITZ) between rebar and concrete. Studies show that, the bond between concrete and steel reinforcement at the interfacial zone is normally very porous, hence promotes corrosion due to ingress of harmful chemicals. This weak and porous zone could be due to insufficient compaction, accumulation of bleeding water (higher effective w/c ratio hence a more open, porous structure at cement-aggregate interface zone (Weiss et al., 2009; Munns, 2010). Therefore good compaction, low porosity and low bleeding at ITZ are vital for controlling corrosion. It is through these aspects that corrosion control techniques are invented and developed. This paper presents the initial findings of the work of improving ITZ through compaction, hence reducing bleeding and increasing bond of concrete and steel using a rebar shaker.

A. Introduction of Rebar Shaker

Rebar Shaking is a process of turning rebars into a vibrator and ensures void free consolidation in congested rebar. The rebar shaking is replacing pencil vibrators (Bennet et al., 2003). This practice leaves steel bars enveloped by cement paste in other words; it creates a paste ring around rebar. The rebar shaker shown in the Figure 1, turns the steel itself into a vibrator. This technique can also be a lifesaver in areas of congested rebar. Figure 2 shows the Cement Paste Ring (CPR) formed after using the rebar as a vibrator. Differences of material composition of bulk concrete and CPR zone in Figure 2 could result into dissimilarity of rates of permeability and diffusion of liquid and gases between these two strata.

Figure 1: Oztec's rebar shaker (Courtesy Oztec 2012)

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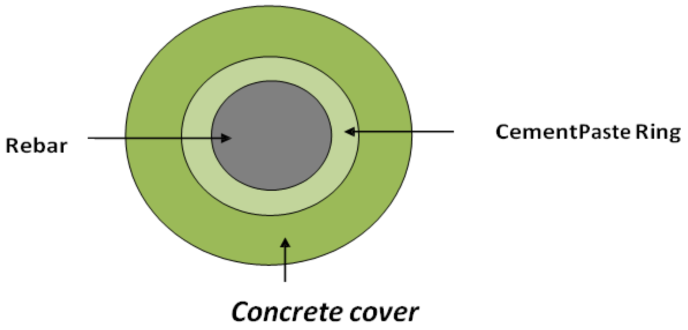

Figure 2: Cement Paste Ring (CPR)

It has been noted that the cement paste ring (CPR) is synonym to Concrete Paste Ring as in reality this zone is comprised of cement, fine sand, fine particles of aggregates and water. It is not just cement and sand as the word depicts.

B. Benefits of CPR and Hypothesis

Permeability of concrete enhances the occurrence of corrosion in RC structures; therefore reducing the permeability of ITZ through improved compaction and use of rich cement paste will reduce the initiation of corrosion in RC structures. Specifically, Improved ITZ will reduce permeability of RC and hence will increase corrosion initiation time. Therefore, the anticipated benefits of this study are:

a) Extension of corrosion initiation time through construction techniques by turning rebar into a vibrator instead of other corrosion control techniques like chemical, biological and electrical methods;
b) Bring out informative parameters that could increase resistance of concrete cover to the corrosion pressure, hence reduce delamination of concrete cover;
c) Increase alternative solutions of controlling and protecting steel bars from corrosion. The success of this study may supplement other methods of corrosion protection and control like mechanical, chemical, biological and electrical;
d) Reduce cost of controlling corrosion problems in infrastructures.

2. EXPERIMENTS AND RESULTS

In order to realize the benefits of CPR towards combating corrosion, preliminary tests have been done to give an indication that may give CPR a merit to be considered for further tests. Initially the task was to establish a relative thickness of CPR which depends mostly on the duration of vibration. Furthermore, pull out tests, determination of W/C ratio at CPR and PH tests were done. The cylindrical RC samples were prepared using rebar shaker as shown in Figure 3.

Figure 3: Cylindrical RC sample

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A. Establishment of CPR thickness

The optimal thickness of cement paste ring is crucial as it govern almost all tests in this study; the longer the vibration duration the thicker the cement paste ring. Table 1, shows the thickness of paste ring with different durations and figure 4 shows various CPR's thicknesses. The CPR of between 5mm to 7mm were adopted that is the vibration duration of 25 seconds to 30 seconds

TABLE 1: DURATION OF VIBRATION VERSUS CPR THICKNESS

Vibration duration (s)	CPR Thickness (mm)
45	10
25	6
15	4
10	3

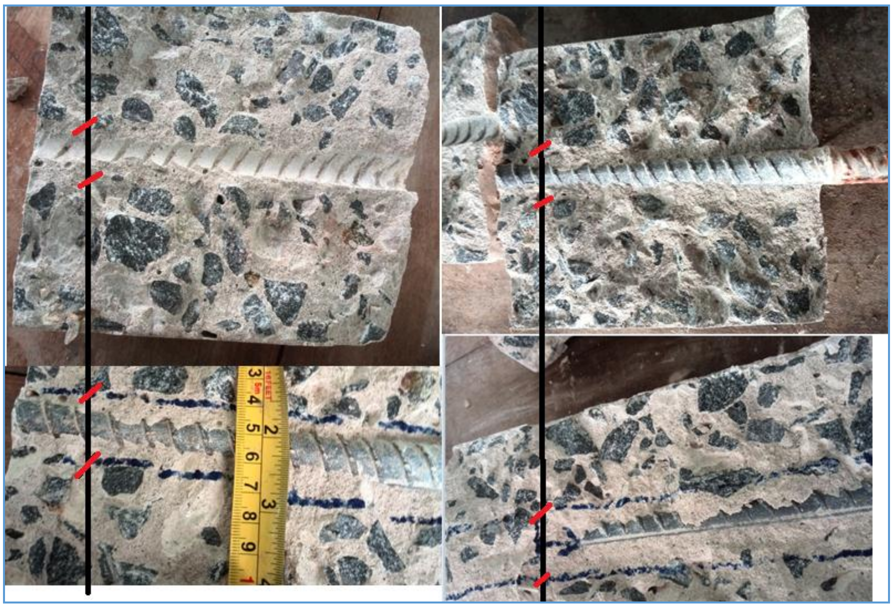

Figure 4: Various thicknesses of Cement Paste Rings

B. Pull-out testing

20 cylinder RC samples of 25MPa were prepared, where by10 samples were vibrated using conventional methods and the other 10 of them were prepared using rebar shaker. The test was done on the 28th day after casting. The aim of this test was firstly, to compare the results of Conventional Pencil Vibrator and Oztec/Rhodes Rebar Shaker, and secondly to evaluate the effects of CPR on the rebar. The basic ingredients of concrete (Cement, sand (<5mm), aggregate (20mm) and water) were used to produce the concrete. The tests were done in accordance to BS 1881. The ribbed rebar of diameter 16mm was used. Figure 5a, 5b and 5c show the samples after Pull out testing for conventional vibration and rebar shaker. The pulls out test results are shown in Table 2.

(a) (b) (c)

Figure 5: Pull-out tests samples

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TABLE 2: PULL OUT TESTS RESULTS OF POKER VIBRATOR VS. REBAR SHAKER

S/No	Compaction Method	Rebar size	Pull out Load (kN)
1	Poker Vibrator	16mm	116
2			110
3			110
4			110
5			115
6			115
7			110
8			110
9			110
1	Oztec/Rhodes Rebar Shaker	16mm	130
2			120
3			125
4			120
5			120
6			126
7			120
8			125
9			123

C. Determination of W/C ratio of CPR

Cement paste ring (CPR) is a thin layer approximated to be around 5mm to 7mm and this layer seems to have W/C ratio as higher as more than 0.4. If this occurs, then this CPR is prone to be more porous than the bulk concrete. Therefore, W/C ratio at this zone needs to be assessed.

Procedures followed on determination of mix ratio of cement paste ring:

i. First and foremost, concrete with mix ratio 1:1.2:2 was produced and poured into cylindrical moulds with 20mm diameter steel bars at the center. Then the mix was put onto an electric vibrator for compaction.
ii. Immediately after compaction the mould was placed on a stand and oztec's rebar shaker was inserted onto the steel bar.
iii. Steel bar should be held in place to ensure it is vertical and centrally oriented during and after vibrations, subsequently switch on the oztec's rebar shaker for 30 - 60 seconds.
iv. Immediately, demolding and extracting the cement paste around the steel bar with spatula was rapidly done as shown on Figure 6.

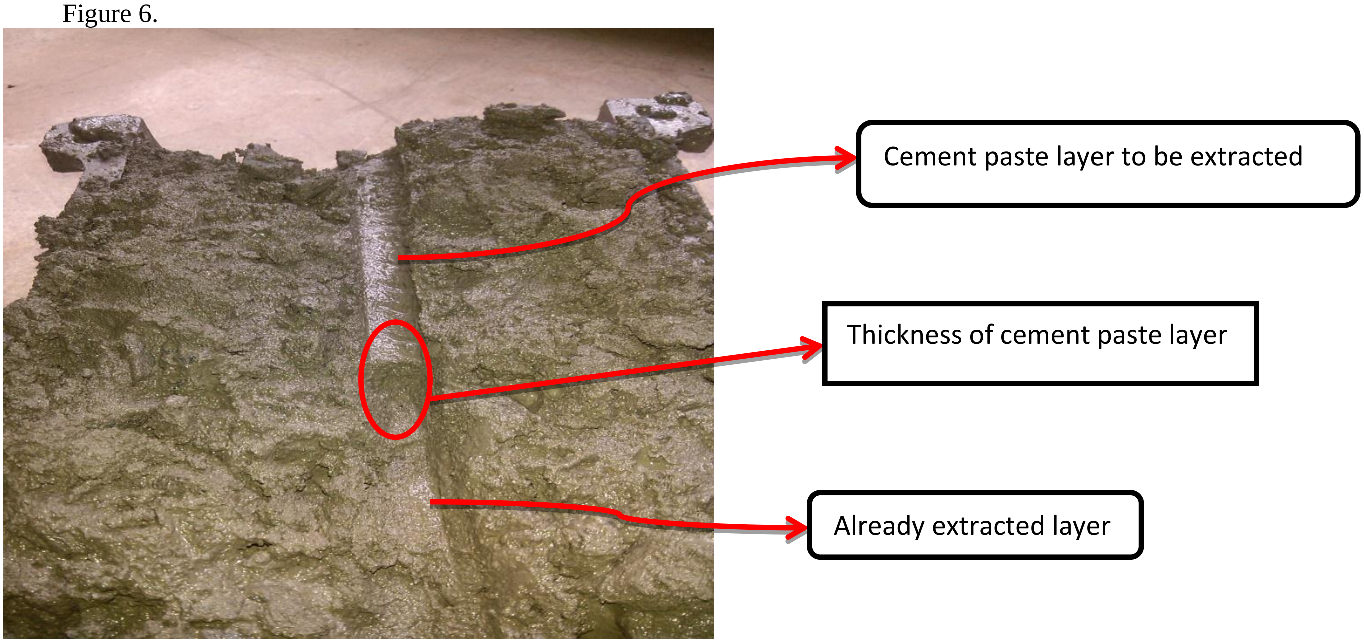

Figure 6: cement paste removal

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v. Measuring the weight of fresh sample of cement paste and inserting the sample to oven for 24hours to determine the moisture content.
vi. Weight of dry sample was measured after 24hrs of oven dry.
vii. Volume measurement was done by displacement method whereby the sample was soaked in water for an hour to fill the pores then immersed into a measuring cylinder to see the volume change
viii. Measuring density of samples
ix. Dehydration Process; heating the sample at 750˚C for 6 hours so as to dehydrate all the water, leaving only sand and cement present.
x. Dry sieving; crushing the sample then sieve it through a 75µm sieve to remove some portion of cement off and retained sample is reacted with HCL.
xi. Washing with HCL; retained sample was washed with 10% HCL then Stirred to increase the reaction between cement and HCL which reacted with cement and thus remained with only sand particles.
xii. Wet sieving; with additional water to neutralize the acid and then sieved via 75µm sieve to remove washed cement that reacted with HCL4
xiii. Oven drying the sample for 24hrs to remove moisture and then recording the weight of dry retained sample(sand particles only)

Three pilot studies were done and it was assumed that water loss during the process was negligible as it is difficult to quantify and the room temperature was 24ºC. Data collection is summarized in the Tables 3 which is also giving results in stages and Table 4.

TABLE 3: DETERMINATION OF W/C RATIO OF CPR

STAGE 1

Sample	Weight of sample as received (gms)	Moisture content Content (%)	Weight of dry sample (after 24 hrs oven dry) (gms)	Volume (m^3)	Density Kg/m^3
Sample A	104.00	10.6	94.00	48	1958
Sample B	122.00	8.9	112.00	55	2036.4

STAGE 2

Heating 750 Degree Celsius (Dehydration process)				Seaving		
Sample	Weight of sample-Dry (gms)	Weight of sample- After Oven Heating (gms)	Loss in Ignition (%)	Loss of Cement (gms)	Sand- Material Material .>75mi (gms)	Coarse/aggregates - Material >3.35mm (gms)
Sample A	94.00	90.00	4.44	17.00	73.00	0
Sample B	112.00	107.00	4.67	21.00	86.00	0

STAGE 3

Washing with Hcl						
Sample	Sand material			C aggregates materials		
	Weight 1(gms)	Weight 2 (Washed) (gms)	Loss (gms)	Weight 1 (gms)	Weight 2(Wash) (gms)	Loss (gms)
Sample A	73.00	56	17.00	0	0	0
Sample B	86.00	64	22.00	0	0	0

STAGE 4 (a)

Result compilation table								
Sample	Impurities (gms)	Material- After Dehydration (gms)	Total lost- Weight Cement (gms)	% by wt	Sand – Material (gms)	Sand- Materials (%)	Coarse/aggregates Materials (gms)	Coarse/aggregates Materials (%)
Sample A	4.00	90.00	34.00	37.8	56.00	62.2	0	0
Sample B	5.00	107.00	43.00	40.2	64.00	59.8	0	0

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STAGE 4 (b)

Cement Content (Cement + Sand Material) =1								
Sample	Density of material (gms)	Impurities (%)	Fraction-Cement (%)	Fraction by wt-cement Kg/m^3	Sand material (%)	Sand material (Kg/m^3)	Coarse/aggregates material (Kg/m^3)	Coarse/ aggregates Material (%)
Sample A	1958.3	4.44	37.8	739.81	62.22	1400.00	0.00	0
Sample B	2036.36	4.67	40.2	818.35	59.81	1280.00	0.00	0

TABLE 4: W/C RATIO RESULTS

	Water content = water loss on oven dry + water loss on ignition (dehydration)		Cement: sand	w/c
Sample A	14.00gms	Sample A	1:1.6	0.41
Sample B	15.00 gms	Sample B	1:1.5	0.35

D. PH tests of fresh concrete

Freshly poured concrete has a pH of 12-13. This pH is due to the formation of calcium hydroxide during the hydration process. The calcium hydroxide then in turn reacts with carbon dioxide in the air, forming calcium carbonate, which reduces pH at the surface. Oakton Meters' pH Meter was used.

Figure 7: PH Measurement

The PH sensor was inserted right at the interface of concrete and rebar 12hours after casting, as shown in Figure 7. The tests were repeated for three different samples of strength of 20MPa, 25MPa and 30MPa, and the results of PH were 12.55, 12.69 and 12.88 respectively. The results were also confirmed by PH paper where, syringe needle were used to pour liquid around steel-concrete interface. This liquid was poured into pH paper which changed the color that matched with PH of 12, as shown in Figure 8.

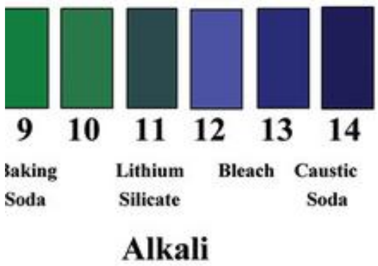

Figure 8: PH paper Scale

3. 0 DISCUSSION OF RESULTS

A.

Thickness of CPR

During the investigations voids were visually observed at the interface of the concrete and rebar for the samples that were consolidated with the Oztec/Rhodes Rebar Shaker, but good complete bond was visually observed with the reinforcing bar. This results into good bond hence greater pull-out load. As the CPR is encased by bulk concrete and remains saturated over a period of time, it implies that hydration will continue for some time hence resulting to the strength increase.

Unlike in conventional consolidation where flat or flaky aggregate trap water and is hard to encase the rebars, but in rebar shaker water at CPR is not trapped by flat or flaky pieces due to fine particles and well graded at CPR zone. No internal bleeding is anticipated on the surface, as the surface of CPR is an interface with reinforcement, on which the CPR stays with water, in what can be called prolonged curing at this state, and the hydration process is not interrupted. Since there is no internal bleeding, therefore the bond between cement paste and reinforcement is good. At CPR zone, bleeding is reduced or eliminated because of proper proportioning of materials, and the presence of fine materials, and in rebar shaking, there is no possibility of excessive segregation as the source of vibration is the rebars itself. The presence of fine particles and saturation state eliminate the formation of capillary cavities (Shetty, 2005).

The prolonged-curing or moist state is a preferred situation for controlling of cracking due to shrinkage, because it is hindering the movement of interlayer water in and out of the laminated structure of the gel particles (Soroka, 2004). This also suggests that there is no possibility of bleeding (Domone, 2003, Kosmatka et al., 2003) at the interface of CPR and reinforcement.

The microstructure properties of the CPR is currently still under investigation but from visual analysis it indicates that the CPR could have different properties and strengths thus giving an idea of 'double cover'. This could be beneficial to combat corrosion. The Model developed by Richardson (2002) suggested the quick and economical model that the severe exposure can be restricted by allowable W/C ratio, minimum cover and minimum cement content as seen in Figure 8(a), and Figure 8(b). This preliminary view may add weight to the prevention side by adding another inner cover.

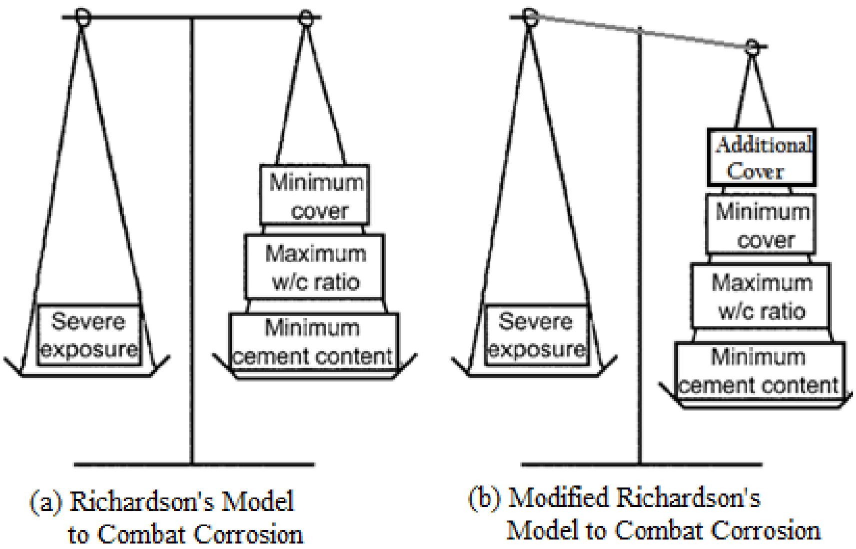

Figure 8: Significance of CPR as additional cover

There are challenges that are current under investigation one of them being micro cracks. Micro cracks in transition zone are a strength limiting factor. Concrete is a brittle material which develops micro cracks even before any load is applied. On account of the dissimilar material, lack of bond, higher W/C ratio, and bleeding water, the transition zone becomes the weakest link in concrete mass. Under load, micro cracks propagate further starting from the largest micro cracks. The micro cracks in the transition zone at the interface with steel reinforcement become more permeable and admits air and water to promote corrosion of steel reinforcement. Incidentally these micro cracks increase the depth of carbonation too.(Shetty, 2005). There is a light at the end of tunnel that, there is no bleeding on this zone, no shrinkage due to prolonged curing, and that even if cracks will occur, there is a possibility of self-healing, the phenomenon which is also under investigation.

B. Pullout tests and bond strength

Generally, there exists a fundamental inverse relationship between porosity and strength of solids. The presence of micro cracks in the interfacial transition zone between the coarse aggregate and the matrix makes concrete a too complex material for prediction of strength by precise strength-porosity relations (this phenomenon could change as we are discussing interface of CPR and reinforcement). The general validity of strength-porosity relation, however, must be respected because porosities of the component phases of concrete, including the interfacial transition zone, indeed become strength-limiting. With concrete containing the conventional low-porosity or high-strength aggregates, the strength of the material will be governed both by the strength of the matrix and the strength of the interfacial transition zone, (Mehta and Monteiro, 2005). It can be easy to portray that the higher the porosity of the concrete the lower the strength and Vice versa. The higher the bond strength of samples which have been vibrated through rebar shaking shows good indication of the void-free/non porous interface zone of the steel and CPR.

In both samples (Poker vibrated and rebar shaker vibrated samples) bond strength is influenced by bar geometries, concrete properties, the presence of confinement around the bar, as well as surface conditions of the bar (ACI 2003). Bond strength is controlled by the following major factors:

i. Adhesion between the concrete and the bar; CPR gluey more and completely to the steel than poker vibrated samples

ii. Friction between the bar surface and concrete; since CPR is completely encasing the rebar, then the friction of steel with CPR is higher than in conventional vibrated concrete

iii. Bearing of the ribs against the concrete;

iv. Gripping effect resulting from the drying shrinkage of the surrounding concrete and the shear interlock between the bar deformations and the surrounding concrete.

Adhesion and friction provide support initially up to a certain force where the adhesion bond is broken, after which the participation of friction diminishes quickly and the mechanical bearing of the ribs on the concrete takes over carrying the entirety of the load. This adhesion bond is only effective the first time the sample is loaded up to the point of adhesion breaking.

The degree to which a bar being developed is confined contributes to the ultimate bond strength of the bar. Radial forces produced by bearing of the concrete on the ribs propagate outwards from the bar, producing tensile stresses in the surrounding concrete. Confinement is provided by both transverse reinforcement and/or additional concrete surrounding the reinforcement which reduces the tensile stresses below the tensile modulus of rupture (Kosmatka et al., 2003).

However, major contribution of bond strength is provided by bearing strength of concrete in front of bar ribs. The ultimate bond failure is a function of concrete compressive strength, cover to the reinforcement or confinement and reinforcing bar profile (Lowes 2003, Amir 2010, Ahmed et al, 2012)

C. *W/C ratio at CPR zone*

A high water/cement ratio will increase the capillary porosity and the rate of carbonation (Mehta and Monteiro, 2005). The hardened cement is characterized by a porous structure, with a minimum porosity of about 28%, which is reached when all the capillary pores become completely filled with the cement gel. This may occur, theoretically at least, in a well-cured paste made with a water to cement (W/C) ratio of about 0·40 or less. Otherwise, the porosity of the paste is much higher due to incomplete hydration and the use of higher w/c ratios. In practice, and under normal conditions, this is usually the case, and porosity in the order of about 50%, and more, is to be expected. Initial determination of the w/c ration at CPR zone shows that it ranging between 0.35 to 0.4, and few shows ranging of up to 0.41. However this is good indication as the w/c higher than 0.4 is not advisable.

D. PH testing results

Concrete shields the entrenched steel reinforcement against corrosion due to the high alkalinity of the pore water of the cement paste. The pH of the pore water varies from 12·5 to 13·5, and under such conditions a thin oxide layer is formed on the surface of the rebars and prevents the iron from dissolving, i.e. corrosion is prevented even in the presence of moisture and oxygen. This protective film is referred to as the 'passive film'. For steel in concrete, the passive corrosion rate is typically 0.1 μm per year. Without the passive film, the steel would corrode at rates at least 1,000 times higher (El-Reedy, 2008). It follows that, as long as the passive film remains intact, the rebars remain protected from corrosion (Soroka., 2004). If the PH falls below 10 by any reason say carbonation, the steel may render the passive film thermodynamically unstable (Glass, 2003). The nature of the porosity and the alkaline reserves of the cement hydration products are the main factors associated with the concrete that affect carbonation. Thus, for example, a high water/cement ratio will increase the capillary porosity and the rate of carbonation. Cracks resulting from tensile stresses in the concrete will also increase the carbonation depth (Glass, 2003) (Mehta and Monteiro, 2005).

4.0 CONCLUSION

From the investigation carried out and discussion above, following are the conclusions

i. CPR has proved to increase bond between concrete and rebar due to good compaction and adhesion of concrete paste on the rebar and prolonged curing.

ii. CPR has proved to have w/c ratio which correspond to the bulk concrete (designed w/c ratio of bulk concrete). These indicate that CPR reduces capillary pores and macro voids because of optimal w/c ratio and good compaction.

iii. A properly consolidated, and cured concrete remains essentially water-tight as long as the micro cracks and pores within the interior do not form an interconnected network of pathways leading to the surface of concrete

iv. The PH range at the Interface of concrete and reinforcement is between 12 and 13, this is giving a warranty of concrete's alkalinity at interface of concrete which protect rebar from corrosion

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