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Study on Durability Performance of Concrete Containing Laterite Aggregates

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Abstract

This paper addresses the durability performance of concrete containing laterite aggregates against corrosion, acid attack and carbonation. Two types of mixes were used, that is plain concrete (0% laterite aggregates) and another one, produced by integrating 20% of laterite aggregate as partial coarse aggregates replacement. Corrosion resistance test was conducted by immersing the 28 days water cured specimens in sodium chloride for 1, 7 and 15 days. The steel bars were then connected to the data logger to determine the corrosion potential of each specimen. The acid resistance of specimens was investigated by immersing them in hydrochloric acid solution and the mass of cubes were measured at every 100 hours and up to 1800 hours. Carbonation depth was determined by spraying phenolphthalein indicator on surface of prism with curing age up to 1 year. The corrosion potential of both types of concrete rose as experimental period become longer. The acid resistance results show that the difference in total mass loss of laterite concrete and control specimen is less than 5%. Carbonation results of the specimens were found to be also close to each other. Utilization of 20% laterite aggregates as partial coarse aggregates replacement influences the resistance of concrete against corrosion, acid attack and carbonation.

Keywords: laterite aggregates; partial coarse aggregates replacement; durability; corrosion; acid attack; carbonation.

1. Introduction

Concrete is a matrix consisting of a binder, fine aggregates, coarse aggregates and water, in specified proportions. Approximately 70% - 80% of the concrete volume is occupied by aggregates [1]. In Malaysia, the extensive use of aggregates from year to year in concrete production [2] as a result of rapid development in construction has led to negative impact to the environment. The high demand of industry for granite aggregates supply causes drastic depletion of natural resources which damaged the environment [3] thus causing ecological imbalance [4]. The depletion of granite aggregate would cause the local industries to depend on imported aggregates and that will lead to higher cost of production. Therefore, the use of alternative aggregates in concrete production is seen as one of the solutions to the serious depletion of granite aggregates problem in the future.

The availability of laterite aggregates in Malaysia [5] has inspired researchers to integrate this red brown colour aggregates as mixing ingredient in concrete. Earlier researcher, Caldeira [6] revealed that content of laterite aggregate used as partial coarse aggregates replacement influences the compressive strength of concrete. However, it is possible to produce concrete with the targeted strength by adding 20% of laterite aggregate as partial coarse aggregates replacement [7]. Study conducted by Kamaruzaman and Muthusamy [8] discovered that concrete containing laterite aggregates exhibits better strength development when subjected to water curing as compared to air curing and natural weather curing. In terms of moisture absorption properties, concrete containing laterite aggregates up to 50% replacement is classified in terms of quality as high quality concrete as plain concrete [9]. The mechanical properties of laterite concrete have been well investigated. However, the behaviour of concrete containing laterite aggregates towards corrosion, acid attack and carbonation is among the aspects that need to be investigated. Thus, this paper addresses the durability performance of laterite concrete that exposed to corrosion, acid environment and carbonation.

2. Experimental Programme

2.1. Materials

Ordinary Portland Cement (OPC), river sand, granite aggregates, tap water, laterite aggregates and high range water reducer are among the materials used to produce the concrete specimens. Superplasticizer in liquid form is used to reduce the water cement ratio while maintaining the concrete workability. Both river sand and granite aggregates were obtained from a local quarry. Laterite aggregates were collected from one of the district in the state of Pahang, West Malaysia. The red brown laterite aggregates which were found on the surface of earth as illustrated in Fig.1 were collected using shovel and then transported to the laboratory. The laterite aggregates were sieved to remove unwanted particles. Both laterite aggregates and granite aggregates used in this experimental work fulfilled the specification in BS EN 12620 [10].

Figure 1. Laterite aggregates on earth surface.

2.2. Mix Proportion and Testing

Two types of concrete mixes of Grade 30 were used. As presented in Table 1, the reference mix (PC) was prepared by using 100 % granite aggregates as coarse aggregates. The second mix, laterite concrete (LC20) was produced by adding 20% of laterite aggregates as partial coarse aggregates replacement.

TABLE 1: MIX PROPORTION OF PLAIN CONCRETE

Material	**kg/m^3**
Ordinary Portland cement	365
Granite	1170
Laterite aggregate	0
Sand	660
Superplasticiser (%)	3.65
Water content	164

2.3. *Testing Procedures*

The investigation on the resistance of concrete to corrosion was conducted similar to the experimental work done by Abosrra *et al.* [11]. 150 mm cubes were cast and steel bar was embedded 60 mm perpendicular from the surface plate of cubes. The specimens were then water-cured until 28 days before subjecting them to the sodium chloride for 1, 7 and 15 days of immersion. The steel bars were then connected to a data logger to determine the corrosion potential of each specimen at every stage using electrochemical method. Acid resistance of concrete was evaluated by immersing 28 days water cured cubes (100 x 100 x 100 mm) in hydrochloric acid solution for 1800 hours. The durability of the specimens towards acid attack was determined by measuring the total mass loss, similar to the experimental approach done by Awal [12].

The depth of carbonated layer was measured as per RILEM CPC-18 [13]. Both specimens, plain concrete (PC) and laterite concrete (LC20) were tested after air cured for 28 and 365 days continuously. At 28 and 365 days of concrete age, the prism specimens with 100 mm x 100 mm x 450 mm were broken off to determine the thickness of carbonated area. The surfaces of concrete specimens were carefully cleaned and brushed from dust and sprayed with the phenolphthalein solution. The non-carbonated area would exhibit purplish colour on the specimens' surface whilst the carbonated area remained unchanged.

3. Results and Discussions

3.1. *Corrosion Test*

Fig. 2 shows the polarization curves of reinforcing steel embedded in the concrete mixes after subjecting to some electrical currents using Potentiostat. The corrosion potentials of reinforcement, E_{Corr} were found to be -0.25 V a day after casting was done, but before subjecting to water curing. The corrosion potential was measured based on the current density obtained at anodic part in the polarization graph. Figs. 3 to 5 exhibit the polarization curves of steel bars in concrete for PC and LC20 after acceleration tests for 1, 7, and 15 days in 3% NaCl solution. After 1 day of corrosion acceleration, the free corrosion potential for PC and LC20 are -0.1 and 0 V, respectively whereas the corrosion current density for PC and LC20 is -4.9 and -4.6 µA/cm^2 respectively. As corrosion acceleration was extended to 7 days, corrosion current density increases to -5.1 µA/cm^2 for PC and -4.9 µA/cm^2 for LC20. The free corrosion potential is -0.12 and 0 V for PC and LC20 respectively. High corrosion acceleration for up to 15 days led to an increase in the corrosion current density and resulted in a reduction of corrosion resistance. Corrosion current density values increase to -5.1 and -5.0 µA/cm^2 for PC and LC20 respectively, after an acceleration of 15 days immersion in sodium chloride.

As the acceleration time increases, the corrosion potential increases. This was due to the ingression of chloride in concrete that had reached the steel surface and indirectly breaking the passivation of that particular steel. On the other hand, the higher strength represented by PC specimens slowed down the corrosion potential due to the passivity achieved as the increase in concrete strength produced less permeability compared to LC20. This is consequently allowing less chloride to be in contact with steel bars. To view in detail, the superior performance of PC in chloride solutions was attributed to the denseness of pore structure that inhibited the penetration of chloride and moisture to the reinforcement and concrete matrix. Presence of higher amount of pores and slightly lower strength of laterite aggregates compared to granite aggregates explains the slightly higher corrosion potential of laterite concrete. The effect of laterite aggregates strength towards concrete durability has been highlighted by Muthusamy and Kamaruzzaman [9].

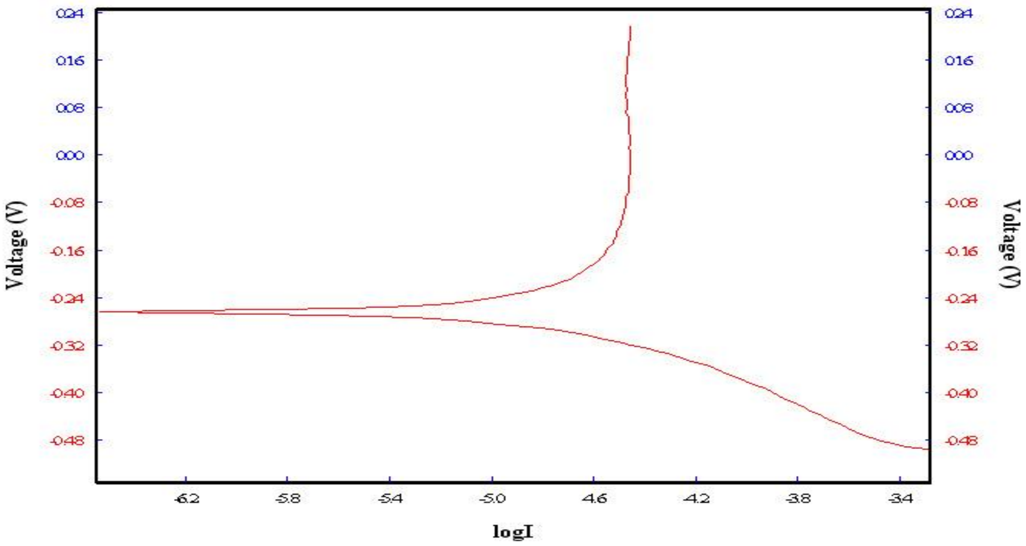

Figure 2. The polarization curves of reinforcing steel embedded in the concrete specimens.

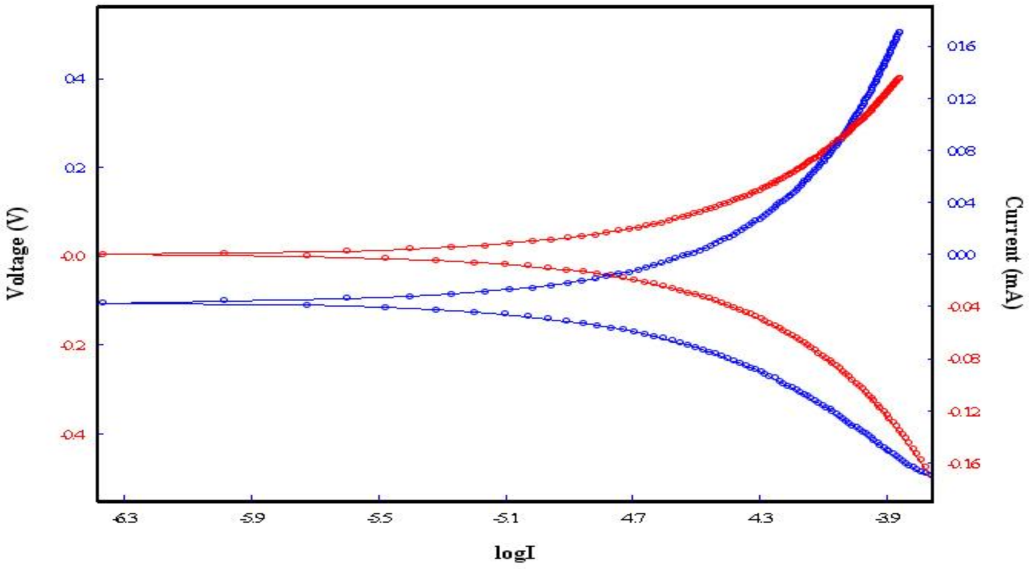

Figure 3. The polarization curves of steel bars in PC and LC20 after acceleration tests for 1 day in 3% NaCl solution.

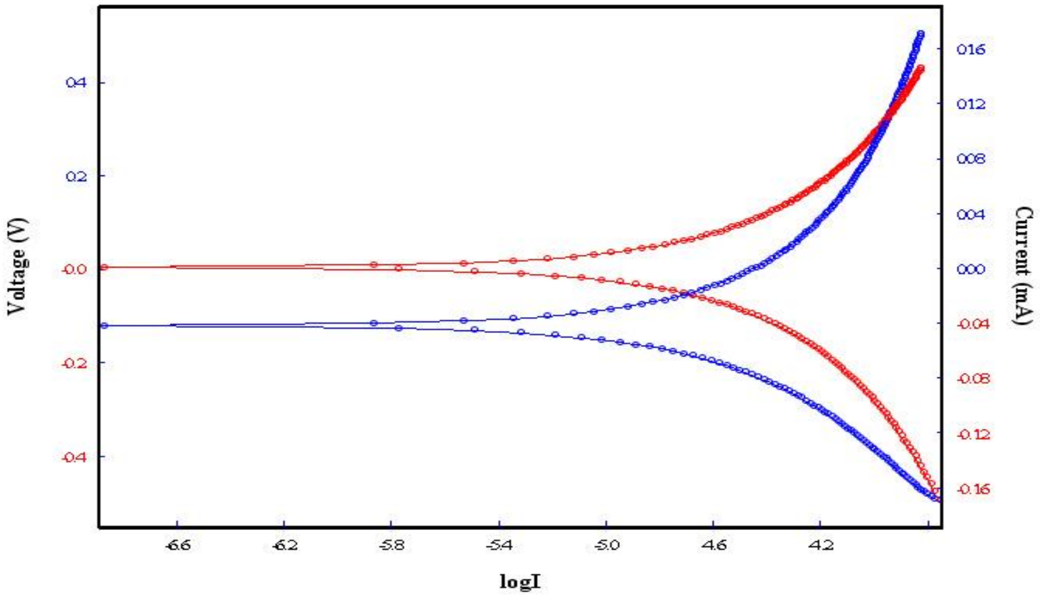

Figure 4. The polarization curves of steel bars in PC and LC20 after acceleration tests for 7 days in 3% NaCl solution.

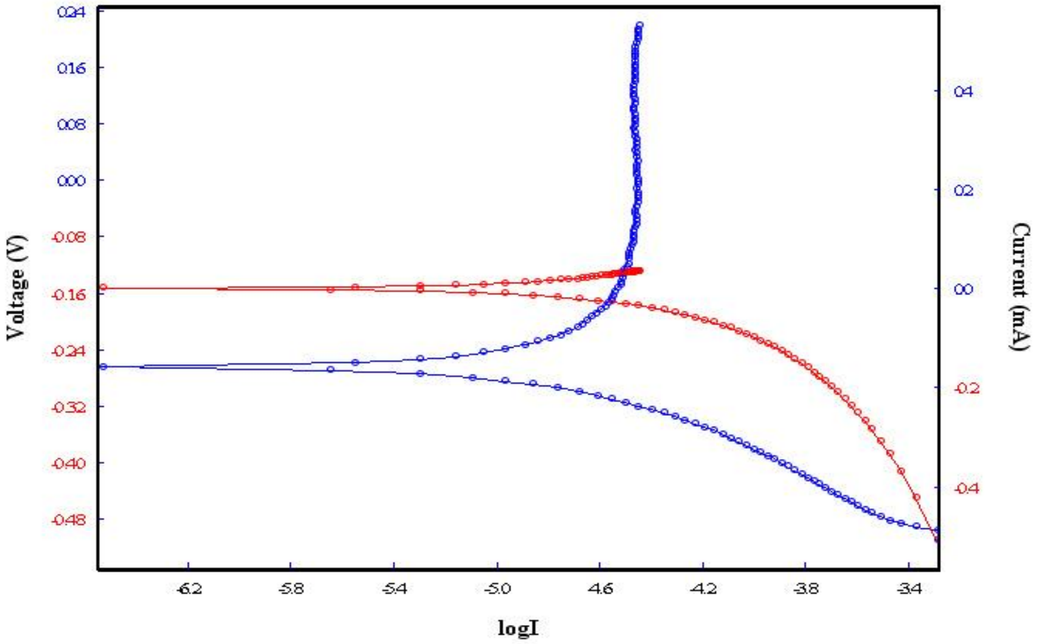

Figure 5. The polarization curves of steel bars in PC and LC20 after acceleration tests for 15 days in 3% NaCl solution.

3.2. Acid Resistance

Generally, changes in the physical appearance of plain concrete (PC) and laterite concrete (LC20) were detected after the specimens were left immersed in acid solutions. Broken edges and corner losses were noticed for both specimens. However, the sign of deterioration is slightly higher in LC20 compared with that of PC. During the early period of immersion, the concrete specimens did not show any change in shape. However, after 300 hours, the edges and corner losses were detected on the LC20 specimens whilst PC specimens were still unaffected, up until 400 hours. The LC20 and PC specimens' losses got slightly higher as the immersion time increased. It was the chemical reaction between calcium hydroxide and hydrochloric acid which attacked their chemical bonding and produced soluble material which resulted in the chipping of concrete. According to Chatveera *et al.* [14] the reaction between calcium hydroxide in the concrete and hydrochloric acid formed calcium chloride, a soluble product which distracted the serviceability of concrete. At the end of testing period, the deterioration in LC20 was higher than that of PC.

The detachment process also caused increment in the pH of solution from 2 to 3. The increase in pH was due to the leaching of calcium hydroxide from the cement matrix into the solution during immersion. Previous researchers [15, 16] found that the calcium hydroxide leached from the cement into the solution contributed to pH changes. It was also observed that there were changes to the colour of the hydrochloric acid solution where the specimens had been immersed. After 300 hours of immersion period, the colour of acid solution started to gradually change into yellow. It was due to the production of calcium chloride in the container. The colour changes in this research was similar to the previous study conducted by Chaudhary *et al*. [17] which revealed that the colour changes of solution only happen if the concrete specimens were immersed in hydrochloric acid. Figs. 6 and 7 exhibit the difference of hydrochloric acid solution at the beginning and the change of colour that took place throughout the experiment.

Fig. 8 compares the weight loss of plain concrete (PC) and laterite concrete (LC20) after immersion in hydrochloric acid solution for 1800 hours. The reading that was taken at 100 hours interval until 1800 hours period showed the increase in weight loss percentage for both PC and LC20 as the immersion time increased. The first 300 hours of immersion indicated that the loss of weight of PC and LC20 was below 0.05%. However after 1800 hours, the PC and LC20 specimens experienced 0.25% and 0.30% weight loss respectively. The weight loss took place due to detachment of the specimens especially at the corner of the cubes resulting from the reaction between acid and calcium hydroxide. This kind of reaction generally occurs where the calcium hydroxide is attacked vigorously [18]. By looking at the weight loss results, laterite concrete (LC20) faced slightly higher deterioration as compared to that of plain concrete (PC). However, acid resistance of LC20 was comparable with PC since Herman [19] stated that the difference in percentage of loss between two data can be neglected if it is below 5%.

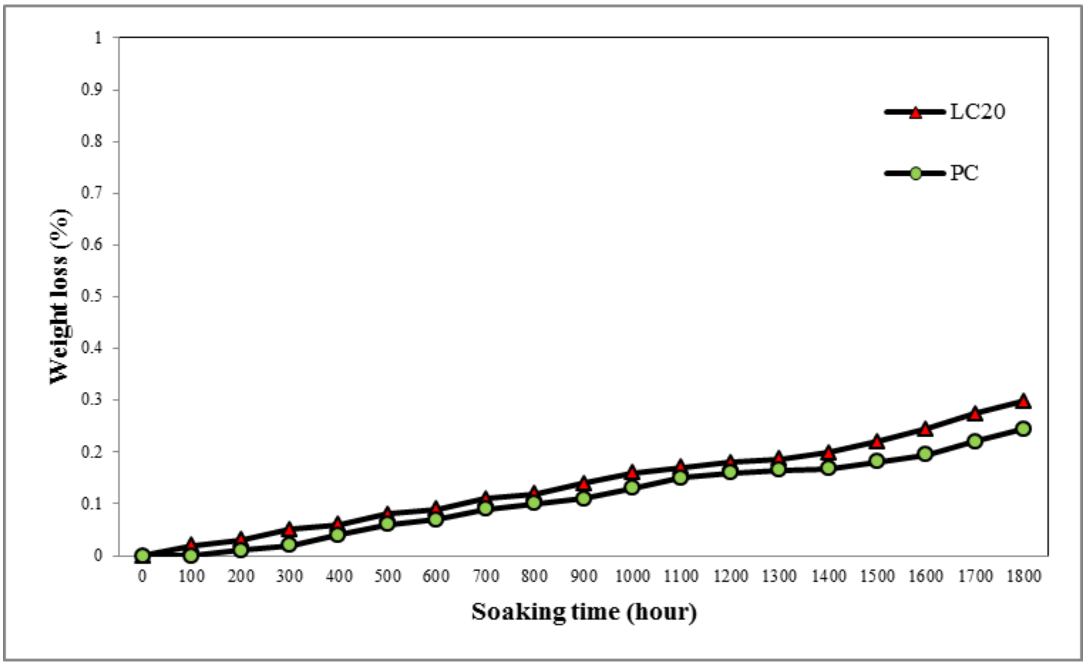

Figure 6. Mass loss of specimens immersed in hydrochloric acid solution.

Figure 7: Colour of hydrochloric acid solution before 300 hours of immersion.

Figure 8: Colour of hydrochloric acid solution after 300 hours of immersion.

3.3. Carbonation

The carbonation results are presented in Fig. 9. At curing age of 28 days, PC specimens produced 1 mm carbonation depth, just as LC20. Both types of specimens produced small readings because of the carbon dioxide that was diffused through the pores inside concrete matrix including the area which in turn carbonated the surface of specimens. At this stage, the hydration process still occurred, retaining concrete moisture but with insufficient exposure to carbon dioxides to create carbonation process [20]. With the existence of moisture, but carbon dioxides remaining in gaseous form, it did react with hydrated cement.

However, at 365 days, the carbonation depth of air-cured specimens increased to 3.2 and 3.4 mm for PC and LC20 specimens respectively. This is because specimens were exposed to air without any introduction of moisture, so the pores became easier to be penetrated by carbon dioxides which was the main factor in a carbonation process. It was highlighted by Jack *et al*. [21] that carbonation depth increases with an increase of carbonation time. Basically, the performance of LC20 is comparable with PC upon carbonation test.

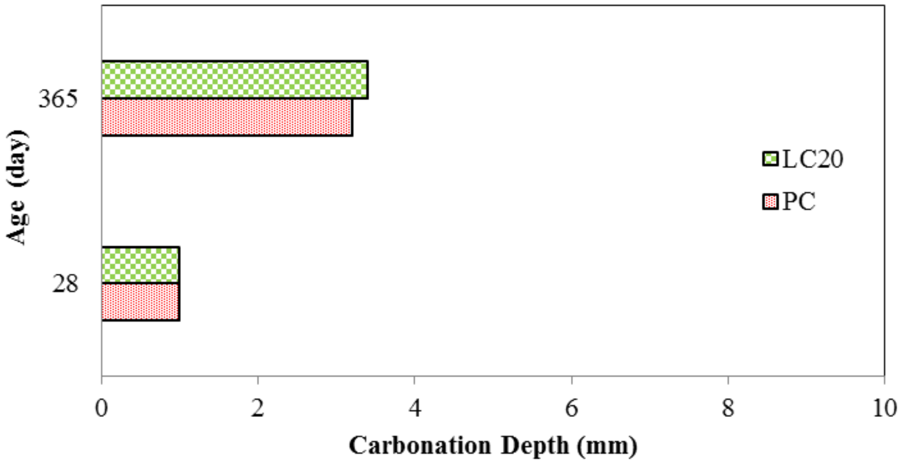

Figure 9. Carbonation depth of specimens up to 1 year.

4. Conclusions

The performance of laterite concrete towards corrosion, acid attack and carbonation is comparable to plain concrete. The results show that laterite concrete has a potential to be used in concrete production commercially. Utilization of laterite aggregates as partial coarse aggregates replacement would reduce the high dependency of concrete industry on granite aggregates supply, and thus maintain the ecological balance and prolong the existence of granite for future generation.

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