Strength, Chloride Permeability and Corrosion of Coarse Fly Ash Concrete with Bagasse-Rice Husk-Wood Ash Additive

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ABSTRACT

This study studied the utilization of Bagasse-Rice Husk-Wood Ash (BRWA) as an additive for improving the strength and durability of coarse Fly Ash (FA) concrete. The ground BRWA was used as an additive for maintaining the consistent slump of FA concrete. The strength, chloride permeability and corrosion resistance were investigated. The chloride permeability of concrete was evaluated using the measurement of coulomb charge as per ASTM C1202 and the corrosion resistance was detected using the Accelerated Corrosion test by Impressed Voltage (ACTIV). The test indicated that the incorporation of ground BRWA as an additive in FA concrete improved potentially both the strength and corrosion resistance, particularly the concrete containing up to 40% FA. While the 60% FA concrete with ground BRWA additive improved significantly in strength, the resistance to corrosion was insignificantly improved. The results showed that the use of ground BRWA as an additive was one approach for its utilization in concrete beyond use as pozzolan. The increase in the use of BRWA in concrete could reduce costs and minimize the environmental problems as well.

Keywords: Coarse Fly Ash, Bagasse-Rice Husk-Wood Ash, Additive, Corrosion, Chloride Permeability, Compressive Strength, Current Passed

1. INTRODUCTION

The durability of reinforced concrete structures is important for a long life, which depends on the concrete's resistance to chemical attacks, physical impacts and the ability of the concrete to protect the reinforcing steel bars against corrosion. Chloride is a principal cause of reinforced steel corrosion in concrete structures. If the ingress of chloride ion into concrete concentrates exceeds a threshold value, the thin passive oxide film around the reinforcement is destroyed. In the presence of oxygen and moisture, the corrosion is then initiated.

Bagasse-Rice Husk-Wood Ash (BRWA) is a by-product obtained from biomass power plants that use bagasse, rice husk and chopped wood and burn them to produce steam for generating electricity to supply the sugar mills. Most of the BRWA is disposed of as waste in landfill which causes environmental problems such as air pollution as well as groundwater quality issues owing to the leaching of metals from the ashes. As-received BRWA has a large particle size, an irregular shape, a highly micro-porous texture and a very high surface area, as shown in **Fig. 1a**. This results in a higher water requirement to maintain workability and a lower compressive strength. However, the BRWA is ground up into fine particles, which partially replaces cement to produce concrete, resulting in an improvement of its compressive strength. The incorporation of ground BRWA not only significantly enhances the strength but also markedly improves the resistance to corrosion. The optimum level of cement replacement is 20% by weight of binder (Horsakulthai *et al*., 2011).

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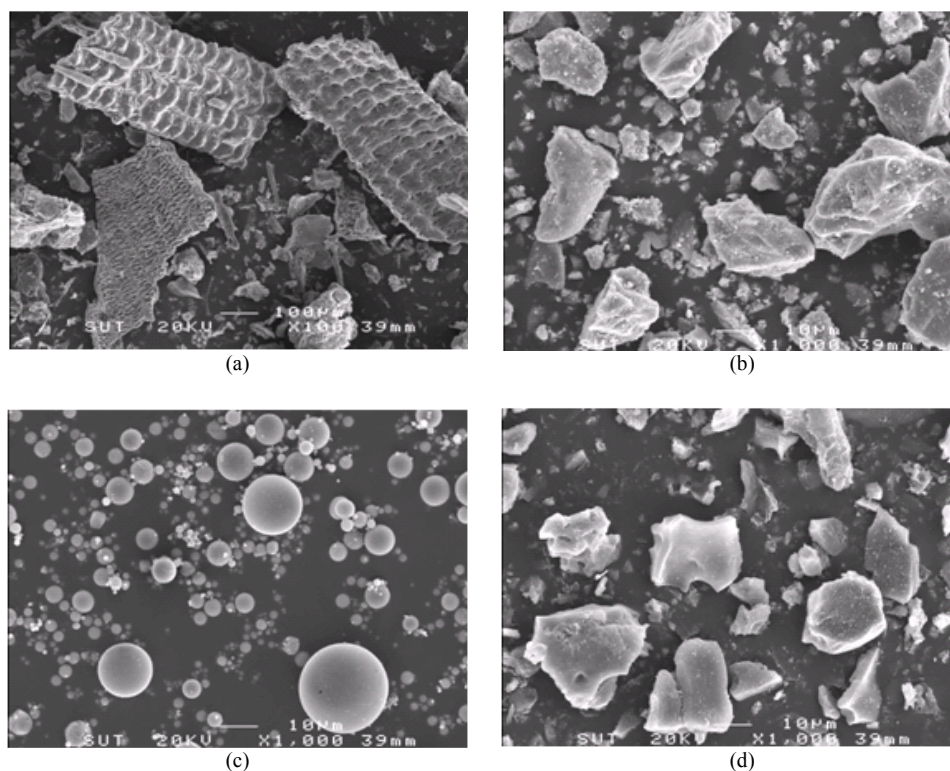
Fig. 1. SEM photo of PC, FA and BRWA, (a) As-received BRWA, (b) PC, (c) FA and (d) Ground BRWA

It is known that Fly Ash (FA) is a very common pozzolan, is a by-product of coal-burning electric power plants and is used worldwide in blended cements. The incorporation of FA results in the reduction of water demand and an increased workability of concrete can also be achieved due to its spherical shape and smooth surface (Peris-Mora *et al*., 1993; Jiang and Malhotra, 2000; Naik and Ramme, 1990). The low development of strength at an early age is a disadvantage of FA blended cement concrete, especially the cement replacements with a high amount of FA and/or coarse FA (Naik and Ramme, 1990; Gopalan, 1993; Erdogdu and Turker, 1998; Paya *et al*., 1995; Lia and Wu, 2005). In recent decades, their disadvantages have been improved by using ternary blended cement, which is combination of Portland Cement (PC), FA and other supplementary cementitious materials, namely, Silica Fume (SF), Rice Husk Ash (RHA), or Metakaolin (MK). The production of concrete with ternary blended PC, FA and SF not only compensates with early strength for the FA concrete, but the FA too enhances the strength development in the long term for SF concretes (Thomas *et al*., 1999). Furthermore, the ternary blended PC, FA and SF have been frequently attributed to synergistic effects taking place between each other, leading to a reduced average pore size of the paste and porosity of the interfacial transition zone between the paste matrix and the aggregates of concrete, thereby increasing the chloride impermeability (Radlinski and Olek, 2012; Poon *et al*., 1999; Wei *et al*., 2007; Shi *et al*., 2011). In addition, the use of ternary blended PC, FA and MK, or PC, FA and RHA results in an increase in strength and durability of the concrete (Wei *et al*., 2007; Shi *et al*., 2011; Mehta, 1988; Isaia, 1999; Bhanumathidas and Mehta, 2001).

The aim of this study is to improve the properties of coarse FA concrete for strength and corrosion resistance due to chloride ions. The ground BRWA is used as an additive materials to increase the fine fraction in concrete. The amount of ground BRWA used compensates for the water requirement of FA for maintaining similar workability when compared to plain concrete. The compressive strength, chloride permeability and corrosion resistance are investigated. The knowledge of the use of ground BRWA as an additive material to improve the strength and the resistance to corrosion of reinforced steel of the FA

concrete will be beneficial for understanding the mechanism as well as for future applications of these materials beyond use as pozzolan in binary blended cement. Furthermore, it reduces in environmental problems and minimizes the requirement of landfill area to dispose of the BRWA.

2. MATERIALS AND METHODS

2.1. Cement

ASTM Type I Portland Cement (PC) was used. Its specific gravity and median particle size were 3.14 and 16.1 μm, respectively. The PC particles were irregular and crushed shape, as shown in **Fig. 1b**. The chemical compositions and gradation are given in **Table 1 and Fig. 2**, respectively.

2.2. Fly Ash (FA)

Lignite FA was a by-product obtained from the Mae Moh power plant in northern Thailand. The FA particles were spherical, solid shapes with a smooth surface, as shown in **Fig. 1c**. The chemical compositions and gradations are given in **Table 1 and Fig. 2**, respectively. It was rather coarse and contained large amounts of calcium oxide at 14%. The median particle size, particle retained on sieve no. 325 (45 μm) and specific gravity of FA were 38.7 μm, 45% and 2.14 respectively. The sum of SiO_2, Al_2O_3 and Fe_2O_3 and the LOI of FA were 76.5 and 0.6% respectively, complying with ASTM (1996-2013c) requirement for a class F pozzolan.

2.3. Bagasse-Rice husk-Wood Ash (BRWA)

BRWA is a by-product obtained from 82.5% bagasse, 15% rice husk and 2.5% chopped wood burnt together at temperatures ranging from 750 to 950°C to produce steam for generating electricity in power plants in northeastern Thailand. The BRWA was ground in a ball mill until the particles retained on sieve no. 325 (45 μm) were less than 1%. The chemical compositions and gradations are given in **Table 1 and Fig. 2**, respectively.

The ground BRWA had a median particle size of 10.5 μm with 0.5% of particles retained on sieve no. 325, while its specific gravity was 2.10. The ground BRWA particle was irregular, with a crushed shape and its textures was slightly porous, as shown in **Fig. 1d**. From **Table 1**, the sum of SiO_2, Al_2O_3 and Fe_2O_3 and the LOI of BRWA were calculated as 82.7 and 3.6%, respectively, complying with ASTM C618 requirements for a natural pozzolan.
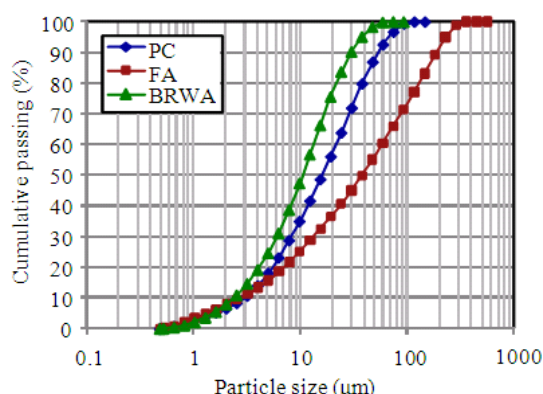

Fig. 2. Particle size distribution of PC, FA and ground BRWA

Table 1. Properties of PC, FA and BRWA

Chemical composition (%)	PC	FA	BRWA
SiO_2	18.10	40.50	78.4
Al_2O_3	4.20	23.70	2.6
Fe_2O_3	3.70	12.30	1.7
CaO	68.30	14.00	7.4
MgO	1.30	2.90	1.3
Na_2O	0.20	1.90	0.2
K_2O	0.40	2.60	3.7
SO_3	3.50	1.50	1.1
LOI	0.30	0.60	3.6
$SiO_2 + Al_2O_3 + Fe_2O_3$	26.00	76.50	82.7
Median size, D_{50} (mm)	16.10	38.70	10.5
Specific Gravity	3.15	2.14	2.1

2.4. Aggregates

20 mm crushed limestone with a specific gravity of 2.77, a fineness modulus of 7.03, dry-rodded unit weight of 1,610 kg/m^3 and water absorption of 1.65% was the coarse aggregate used. Washed river sand with a specific gravity of 2.60, a fineness modulus of 2.56 and water absorption of 0.65% was the fine aggregate used. Their gradations conformed to requirement of the ASTM (1996-2013a).

2.5. Mix Proportions

Normal strength concretes with a water-to-binder ratio (w/b) of 0.50 were used. The Portland cement was partially replaced with FA at dosage of 20, 40 and 60% by weight of binder. They were controlled in similar slumps ranging from 50 mm to 100 mm. Two series of FA concretes with similar slumps were used; the first group was constituted of reduced water content and constant w/b; in the second group, ground BRWA was used as an additive for compensating the water requirements of the FA. The compositions of the concrete mixes are given in **Table 2**.

Table 2. Mix composition of concretes with w/b of 0.50

| Mix | Slump (mm) | Composition (kg/m^3) | | | | | |
		Cement	FA	BRWA	Sand	C. agg.	Water
PC	80	380	-	-	767	1,037	190
20FA	65	288	72	-	783	1,037	180
40FA	70	210	140	-	772	1,037	175
60FA	95	136	204	-	770	1,037	170
20FA-B	80	304	76	32	697	1,037	190
40FA-B	60	228	152	48	650	1,037	190
60FA-B	70	152	228	67	593	1,037	190

2.6. Concrete Casting and Curing

Cylinder concretes of 100 mm diameter and 200 mm height were cast in two layers, each layer was rodded 25 times with a 10 mm diameter rod and vibrated by a vibrating table for 5 sec. After 24 h, they were demoulded and cured in water till the period of testing.

2.7. Compressive Strength Test

The compressive strength test was conducted by crushing three cylindrical concrete specimens of 100 mm diameter and 200 mm height at 7 days, 28 days and 90 days in accordance with ASTM (1996-2013b). The average of the three tests at each period was reported.

2.8. Rapid Chloride Permeability Test (RCPT)

After 7 days, 28 days and 90 days, the cylindrical concrete specimens of 100 mm diameter and 200 mm height were cut into 50 mm thick slices. The two inner slices were prepared and preconditioned, as described in ASTM (1996-2013d). The prepared cylinders were set up as shown in **Fig. 3** and a 60 v direct current was applied across the cell. The current passed was measured every 30 min for 6 h and the total coulomb charges through at the end of 6 h were reported. The RCPT was performed in accordance with ASTM C1202. The coulomb charge report was an average of two tests at each period.

2.9. Accelerated Corrosion Test by Impressed Voltage (ACTIV)

Cylindrical concrete specimens of 100 mm diameter and 200 mm height with a centrally embedded rebar of 12 mm diameter and 200 mm length were subjected to impressed voltage test in accordance with NTB (1989). They were partially immersed in 3% NaCl solution and the circuit was connected with the embedded steel being the anode and an external stainless steel sheet being the cathode by applying a constant 5 v direct current, as shown in **Fig. 4**. The variation of current was recorded once a day until the concrete specimen initiated cracks.
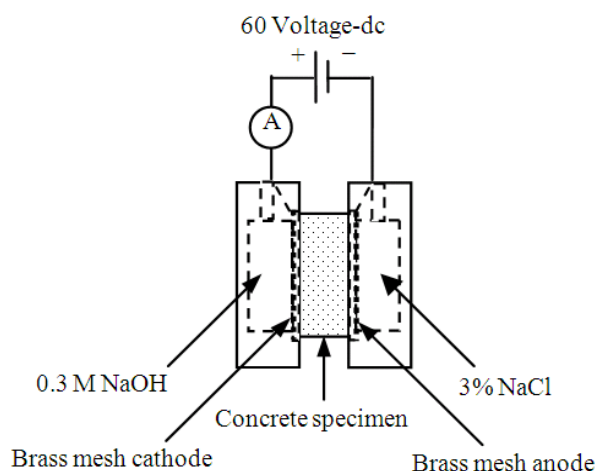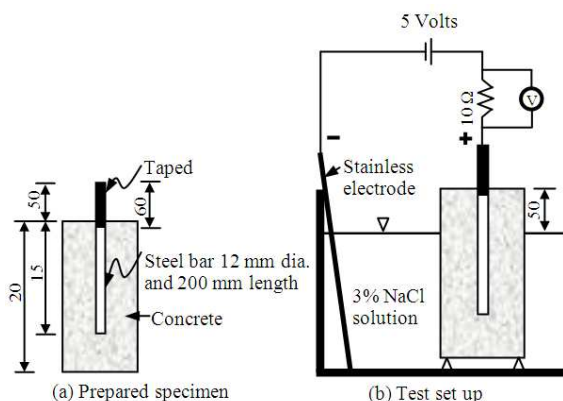

Fig. 3. RPCT test set up

Fig. 4. Accelerated corrosion test by impressed voltage

3. RESULTS AND DISCUSSION

3.1. Water Content and Ground BRWA Content

A reasonable reduction in the water requirement of FA concrete was observed as the amount of FA increased in concrete with similar slumps. The water content of PC, 20FA, 40FA and 60FA was 190, 180, 175 and 170 kg/m^3, respectively. This resulted from the characteristics of FA, namely the spherical, solid shape and a smooth surface. On the contrary, the ground BRWA had a higher water requirement, which was used to compensate for the water requirement of the FA concrete.

The result of the mix proportion in **Table 2** indicates that the increase in the amount of FA in the concrete resulted in the increase in the amount of the ground BWRA additive for maintaining similar slumps. The

ground BRWA additive was added to the binder content at 8.5, 12.5 and 17.5% of the binder by weight for 20FA-B, 40FA-B and 60FA-B concrete, respectively.

3.2. Compressive Strengths

The effect of ground BRWA additive on the compressive strength of coarse FA concrete is given in **Table 3**. The compressive strength of PC concrete was 30.4, 38.2 and 45.5 MPa at 7 days, 28 days and 90 days, respectively. The incorporation of the ground BRWA additive improved both the early and long-term strength of coarse FA concrete. At 7 days, the compressive strength of coarse FA concrete containing ground BRWA additive increased from 79.3 to 100.3, from 60.9 to 76.3 and from 36.2 to 50.3% for 20FA, 40FA and 60FA, respectively, compared to the PC concrete. This was a reasonable increase in the compressive strength due to the effect of the fineness of the ground BRWA, which was higher than that of PC and FA, as shown in **Fig. 2**, to play the microfiller. The strength of FA concrete with the ground BRWA additive continuously increased during the period from 7 days to 90 days, with the normalized strength of 111, 100.2 and 73.8% for 20FA-B, 40FA-B and 60FA-B, respectively, whereas the normalized strength of 20FA, 40FA and 60FA was 95.4, 81.3 and 58.2%, respectively. This indicated that both FA and the ground BRWA reacted with calcium hydroxide, obtained from cement hydration, to form a Calcium Silicate Hydrate (C-S-H) and the strength developed from the synergistic effect of FA and ground BRWA as well.

3.3. Chloride Permeability

As presented in **Fig. 5**, at the early stage of 7 days, the incorporation of the ground BRWA additive in the FA concrete insignificantly improved the resistance to chloride permeability, except in the mix of high volume FA concrete with 60% FA, which showed a marked reduction in the coulomb charge from 6,410 to 4,030, or reduced by 37%. The advantage of addition the ground BRWA additive showed potential at 28 days in that the coulomb charge reduced from 3,400 to 2,595, from 1,845 to 1,530 and from 2,680 to 1,500 for the concrete containing 20, 40 and 60% FA, respectively. However, the FA concrete containing the ground BRWA additive insignificantly changed with respect to the coulomb charge for 40FA and 60FA at 90 days. The charge passed was about 465 coulombs to 625 coulombs, which was classified as a very low level of chloride ion penetrability, according to the ASTM C1202.

3.4. Results of ACTIV

3.4.1. Initial Current and Time of Initial Crack

The results of the initial current and the time of initial crack are presented in **Table 4**, **Fig. 6-8**. The initial current of PC concrete was 18.9 mA with the highest rate of current passed. After incorporating FA at dosages of 20, 40 and 60% (20FA, 40FA and 60FA, respectively), the initial current could be reduced to 18.0 mA, 12.1 mA and 12.3 mA, respectively. There was a similar trend in chloride permeability in the total charge passed at 28 days, which was when immersion started. The decrease in the initial current was due to an increase in the electrical resistance due to the reduced pore size of the cement paste and decreased interfacial porosity, which made it difficult for the current passed to flow (Poon *et al.*, 1999). The use of ground BRWA additive in the FA concrete was more effective in the increase in the electrical resistance, which resulted in the reduction of the initial current to 11.3 mA, 8.4 mA and 10.2 mA, for 20FA-B, 40FA-B and 60FA-B, respectively.

The time of the initial crack of the PC concrete was the lowest at 26 days, in 20FA, 60FA and 40FA at 32 days, 36 days and 42 days, respectively. This conforms to the trend of the initial current. After adding the ground BRWA additive, the time of the initial crack of 20FA-B and 40FA-B was increased to 74 days and 99 days, respectively. This was reasonable, considering the decrease of the initial current, but the 60FA-B inversely reduced the time of the initial crack to 33 days although the initial current was lower than that of 20FA-B and 60FA. This result might be because the strength of the passive film around the embedded steel was not adequately strong at 28 days.

3.5. Characteristic of Corrosion Current of Concrete

The relationships between the time of immersion and the current are presented in **Fig. 6-8** from the investigation of the current at various times, it can be classified into three stages. An initial current decreased with time, which is the first stage. This could be attributed to the layer of passive iron oxide film which formed due to the reaction of cement and water. The passive film did not actually stop the corrosion, but reduced the corrosion rate to an insignificant level (ACI, 2001). At this stage, the initial current value depended on the transport property of the concrete, which is described by the charge passed and chloride diffusion coefficient. The second stage was started during a period of constant current value, except for relatively small current variations.
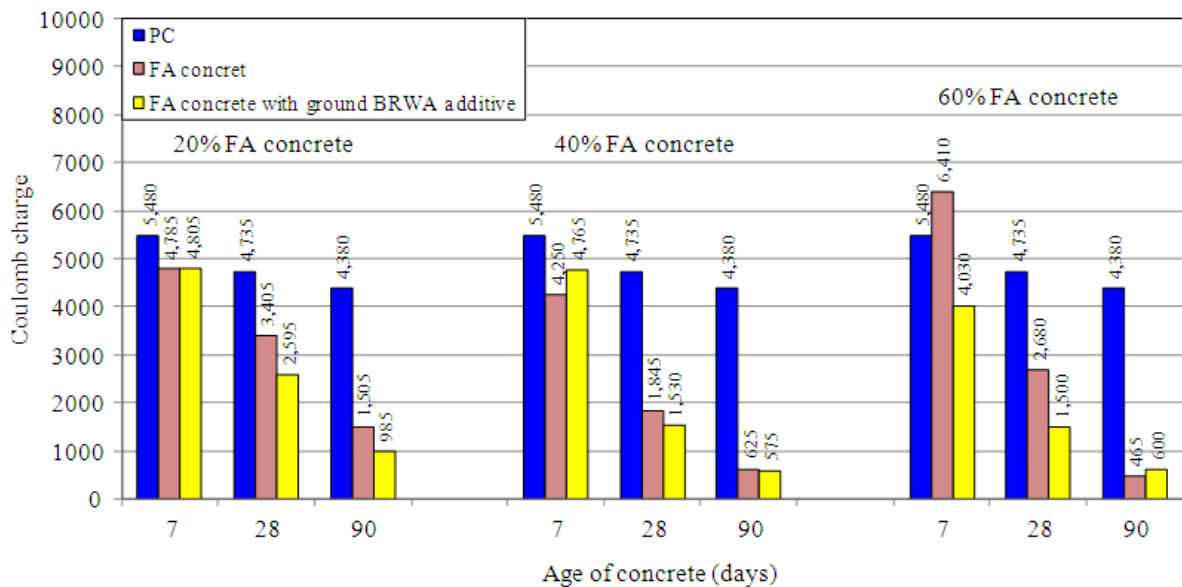
Fig. 5. Charge passed of concrete

Table 3. Compressive strength of concrete

	Compressive strength (MPa)-Normalized		
Mixes	7 days	28 days	90 days
PC	30.4-100	38.2-100	45.5-100
20FA	24.1-79.3	30.5-79.8	43.4-95.4
40FA	18.5-60.9	25.0-65.4	37.0-81.3
60FA	11.0-36.2	17.6-46.1	26.5-58.2
20FA-B	30.5-100.3	38.8-102	50.3-111
40FA-B	23.2-76.3	31.2-81.7	45.6-100.2
60FA-B	15.3-50.3	21.0-55.0	33.6-73.8

Table 4. Initial current and time of initial crack of concrete

Mixes	Initial current (mA)	Time of initial crack (days)
PC	18.9	26
20FA	18.0	32
40FA	12.1	42
60FA	12.3	36
20FA-B	11.3	74
40FA-B	8.4	99
60FA-B	10.2	33

The duration of this period was defined by the strength of the passive film and also the denseness of interfacial transition zone between the matrix and the reinforcing steel (ACI, 2001; Soylev and Francois, 2003). The third stage was when the current suddenly increased due to the micro-crack initiated before the initial crack appeared. After this, the current continued to increase.
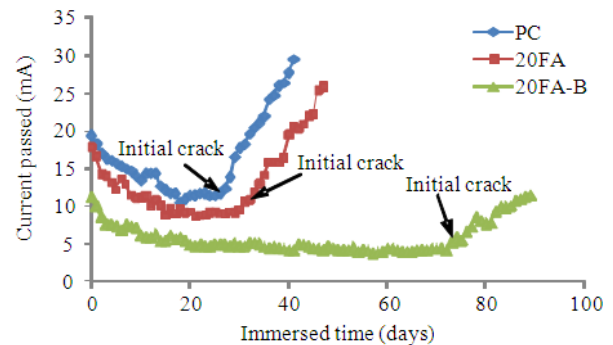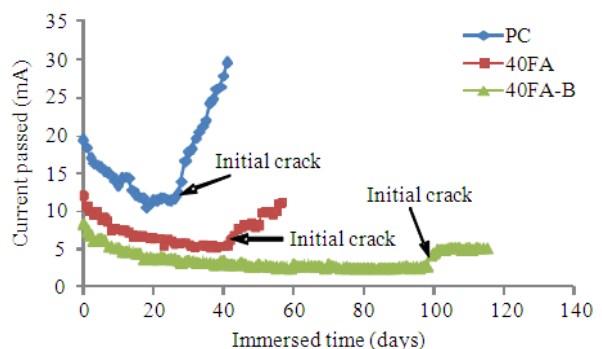

Fig. 6. Corrosion current of Concrete containing 20% FA

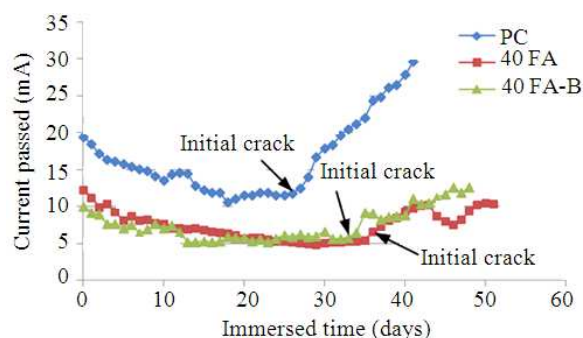**Fig. 7.** Corrosion current of Concrete containing 40% FA

Fig. 8. Corrosion current of Concrete containing 60% FA

In this stage, the region of the passive film started to break down locally, then more chloride ions were attracted to this area and hence, the local concentration of the chloride ions increased and initiated corrosion, resulting in the sudden increase of current (NTB, 1989; ACI, 2001).

4. CONCLUSION

The following conclusions may be drawn based on the results obtained from this study:

- The use of ground BRWA as an additive in FA concrete improved both the early and long term strength. Furthermore, it could reduce the bleeding of FA concrete, particularly in high volume FA concrete
- The concrete containing up to 40% FA with the ground BRWA additive significantly improved in strength, chloride permeability and corrosion resistance compared to concrete with the same level of FA, while the concrete containing 60% FA with the ground BRWA additive only improved in strength, but the resistance to corrosion was insignificantly improved
- The use of ground BRWA as additive was one approach for its utilization in concrete beyond use as pozzolan. The increase in the use of BRWA could reduce environmental problems and minimize the requirements of landfill area to dispose of the BRWA

5. ACKNOWLEDGMENT

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