PROPERTIES OF SELF COMPACTING CONCRETE MADE WITH BOILER BURNT HUSK ASH

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ABSTRACT

This study investigates the properties of self-compacting concrete (SCC) incorporating Local Ash in replacement of commercial Fly Ash (FA). Locally available Ash prepared from the boiler burnt husk residue was collected from an integrated MSW thermal power plants and rice mill. An equivalent gradation matching the commercial FA was then prepared and the mechanical and physical properties were examined for optimal level of replacement to investigate the grinding effect on the pozzolanic reactivity of Local Ash. Physical properties were evaluated by slump flow test, V-funnel test and L-Box tests and mechanical property was evaluated by compressive strength test on Ø-4"x8" cylinders. The durability properties were also evaluated in terms of total charge passed through the concrete as measured by rapid chloride permeability test (RCPT). Compressive strength and permeability properties of SCC made with equivalent Local Ash was comparable to that of the reference SCC made with commercial FA. Due to the increased pozzolanic effects, reduced average pore-size in the paste, and the improved interfacial zone of modified Local Ash content, Compressive strength of SCC made with modified Local Ash was more than 90% of the reference SCC made with commercial FA, while the permeability by RCPT was 6% higher in the former. The SCC with Local Ash also passed the other rheological requirements, suggesting a promising scope of Local Ash to be used for more economic SCC production..

Keywords: *self-compacting concrete, fly ash replacement, strength, chloride ion permeability*

1. INTRODUCTION

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction, a relatively new category of high performance concrete, is proportioned such that the concrete freely passes around and through reinforcement, completely fills the formwork and consolidates under its own weight without segregation or bleeding. SCC generally has higher powder content than conventionally compacted concrete. The common practice to obtain self-consolidation behaviour in SCC is to limit the coarse aggregate content, reduction of maximum size of aggregates and use of super plasticizer. One of the consequence of reducing coarse aggregate content was reported as the increase of the mortar content in the mixture. The chemical admixtures are generally high-range water reducers (super plasticizers) and viscosity-modifying agents, which can change the rheological properties of concrete mixture. Mineral admixtures are used as an extra fine material besides cement, and in some cases, they replace cement.

The main disadvantage of self-compacting concrete is mainly associated with its production cost due to incorporation of high volume Portland cement and chemical admixtures. The use of large quantity of cement increases its cost and results in a greater temperature rise. the use of mineral admixtures such as fly ash (FA), blast furnace slag, or limestone filler could increase the slump of the concrete mix without increasing its cost (ACM Centre, 2001– 2004). Furthermore, in context of global carbon dioxide emissions, cement production was estimated to emit 829 million metric tons of CO_2 (MMT CO_2), about 3.4% of global CO_2 emissions (Schlagbaum, T., 2002). Portland cement concrete has high energy consumption and emissions associated with its manufacture, which is reduced by use of supplementary cementitious materials. It also ensures an economical and sustainable concrete (Dietz, J. and J. Ma, 2000). Supplementary cementitious materials (SCMs) can also be used for improved concrete performance in its fresh and hardened state. They are primarily used for improved work-ability, durability and strength. These materials allow the concrete producer to design and modify the concrete mixture to suit the desired application (Bartos, J. M., 2000). Concrete mixtures with high Portland cement contents are susceptible to cracking and increased heat generation. These effects can be controlled to a certain degree by using SCMs. Fly ash, slag and silica fume enable the concrete industry to use hundreds of millions of tons of by-product materials that would otherwise be landfilled as waste. Furthermore, their uses reduce the consumption of Portland cement per unit volume of concrete (ASTM C 618, 2003).

Boiler burnt husk ashes (BBHA), a by-product of rice processing industry, causes environmental pollution while the cost of storage of such ash is very high. In Bangladesh, the annual BBHA production is approximately 15 million tons more than the rest of all industrial waste in the country. The amount of BBHA produced today cannot be ignored. Options available for BBHA handling are disposal and utilization. The BBHA is a resource material, if not managed well, this may pose environmental and health problems (Dhir and Dyer, 1999).

In recent years, Fly Ash produced from coal combustion in thermal power plants, has been used successfully as a SCM for producing SCC, while the BBHA, so far, has been simply dispersed into the atmosphere as redundant. This study investigates the incorporation of Local Ash for production of self-compacting concrete (Tahir and Chaudhry, 2004). In this study, an attempt was also made to study the effect of FA on the compressive strength and chloride permeability of SCC.

2. EXPERIMENTAL PROGRAM

The three main fresh properties of SCC in plastic state are filling ability (excellent deformability), passing ability (ability to pass reinforcement without blocking) and high resistance to segregation. The filling ability or flow ability is the property that characterizes the ability of the SCC of flowing into formwork and filling all space under its own weight, guaranteeing total covering of the reinforcement (Khayat, K.H., 1999). The mechanisms that govern this property are high fluidity and cohesion of the mixture. The passing ability is the property that characterizes the ability of the SCC to pass between obstacles- gaps between reinforcement, holes, and narrow sections, without blocking. Stability or resistance to the segregation is the property that characterizes the ability of the SCC to avoid the segregation of its components, such as the coarse aggregates. Such a property provides uniformity of the mixture during transport, placement and consolidation. The mechanisms that govern this property are the viscosity and cohesion of the mixture. Self-compacting concrete must meet the requirements of 1 and 2 while its original composition remains uniform. The key properties must be maintained at adequate levels for the required period of time (e.g.20 min) after completion of mixing.

Performance of the SCC made with local BBHA was determined in terms of its physical and mechanical properties. The physical properties of the raw BBHA was determined in terms of its Blaine fineness and it was then ground in a laboratory ball mill to further refine the grains to improve the fineness. Slump flow test, V-funnel test and L-box test were performed to determine the rheological properties of fresh concrete; compressive strength test was performed to determine the mechanical properties and rapid chloride permeability test (RCPT) was performed to determine the permeability of the SCC.

3. RESULTS & DISCUSSIONS

The result of various fresh properties was determined by slump flow test (slump flow diameter and T_{50cm}), L-box test (time taken to reach 400 mm distance T_{400mm}, and time taken to reach 800 mm distance T_L, ratio of heights at the two edges of L-box (H_2/H_1)); V-funnel test (time taken by concrete to flow through V-funnel after 10s T_{10s}, time taken by concrete to flow through V-funnel after 5 minT_{5min}) (Dietz, J. and J. Ma, 2000).

3.1 Blaine Fineness

The Blaine fineness, which is defined as a measure of the particle size or fineness of cement and supplementary cementitious materials.

$$S\,(cm2/gm) = \frac{Ss\sqrt{T}}{\sqrt{Ts}} \tag{1}$$

Where, S = Sample fineness; S_s = Standard cement fineness (3830 cm^2 / gm); T = Time of flow of air through the sample; T_S = Standard time (90 sec)

Table 1: Blaine fineness modulus of FA

Sample Type	Blaine fineness (cm^2/ gm)
Industrial FA	2100
Local Ash	1140
Modified Local Ash	1775

3.2 Slump Flow Test

The slump flow test judges the capability of concrete to deform under its own weight against the friction of the surface with no restraint present (Bartos, J. M., 2000). All the mixes in the present study conform to the above range since the slump flow of SCC mixes was in the range of 600–700 mm. The slump flow time for the concrete to reach diameter of 500 mm for all the mixes were less than 4.5s.

Figure 1 shows that SCC made with commercial FA possess high slump flow, indicating highest capability to deform under its own weight against the friction of the surface with no restraint present whereas Local Ash gives lowest slump flow result. As noticed in bar chart that if the Local Ash can be modified equivalent to a finer Commercial FA, the slump value increases to a great extent due to finer FA particle content that helps paste to move easily.

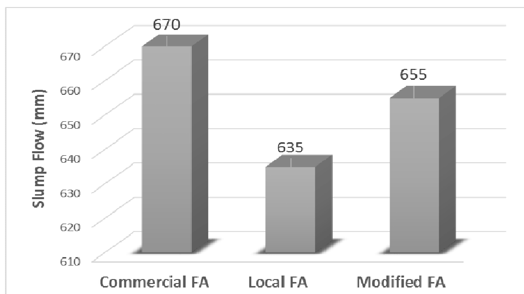

Figure 1: Slump Flow Test

3.3 V-funnel test

V-funnel test was also performed to assess the flow ability and stability of the SCC. V-funnel time, which is less than 6s, is recommended for concrete to qualify as a SCC. As per EFNARC, time ranging from 6 to 12s was considered adequate for a SCC. From the test result, The V-funnel flow times were in the range of 4–10s for SCC indicating that modified Local Ash certify more flow-able concrete than Local Ash referring The more the finer fly ash the more the flow-ability attained by the fresh concrete (Naik, T. R. and S. Singh, 1997)

3.4 L-Box test

Maximum size of coarse aggregate was kept as 20 mm in order to avoid blocking effect in the L-box. The gap between rebar in L-box test was 35 mm. The L-box ratio H_2/H_1 for the mixes was above 0.8 which is as per EFNARC standards. A bar chart was provided below to show the ratio of heights at the two edges of L-box (H2/H1) V-funnel test result for Commercial, local and modified Local Ash (Bartos, J. M., 2000).

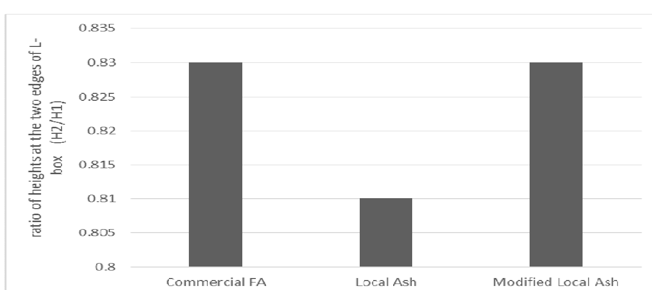

Figure 2: L-Box Test

Figure 2 shows that commercial FA and modified Local Ash assess the equal passing ability to flow through tight openings where Local Ash gives the lowest value. All The reported results are the average of the two sample mixes.

3.5 Compressive Strength Result

Compressive strength test gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. Compressive strength tests were performed on the cube specimens at the ages of 7 and 28. Figure 3 shows the failure pattern of the specimen.

Figure 3: Failure Pattern of the Specimen

The compressive strength at 7days and 28days results of hardened concrete made with commercial, local and modified Local Ash are compared through a bar chart below. The reported compressive strength is the average of 6 values.

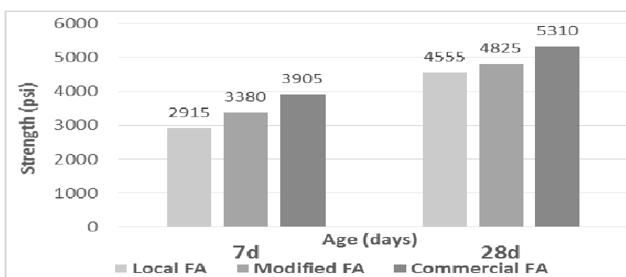

Figure 4: Compressive strength development Comparison of SCC

Figure 4 shows Compressive strength of SCC made with equivalent Local Ash was more than 90% of the reference SCC made with commercial FA. Moreover, the compressive strength made with Local Ash are 25% and 14% less than the reference SCC made with commercial FA at 7 and 28 days respectively due to coarser particle size of Local Ash. An increase of about 16% and 6% compressive strength of SCC made with modified Local Ash was observed at 7 and 28 days respectively, due to the reduction in particle size of Local Ash matched with commercial FA by ball mill method, compared to SCC made with Local Ash. Therefore, it could be concluded that the processed Modified Local Ash particles in the mixtures increases the compressive strength of SCC. Further it was noticed that the average variation between the compressive strength of SCC made with commercial and modified Local Ash is about 16% and 10% at 7 and 28 days which indicates a potential chance of replacing commercial FA with Local Ash to get economical & reliable SCC to use.

3.6 Chloride Ion Permeability Test Results

The ability of concrete to resist the penetration of chloride ions is a critical parameter in determining the service life of steel-reinforced concrete structures exposed to dicing salts or marine environments.

The diffusion cell consists of two chambers. NaCl solution of concentration 2.4M and NaOH solution concentration 0.3 M are prepared. NaCl solution concentration 2.4M is filled in one chamber and in another chamber 0.3 M NaOH solution is taken. This test method consists of monitoring the amount of electrical current passed through 2-in. (51-mm) thick slices of 4-in. (102-mm) nominal diameter cores or cylinders during a 6-h period. A potential difference of 60 31 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration (Amrutha, Nayak, Mattur C. Narasimhan and S.V.Rajeeva).

Figure 5: RCPT-Test Setup

The procedure of this test method for measuring the resistance of concrete to chloride ion penetration has no bias because the value of this resistance can be defined only in terms of a test method. The method relies on the results from a test in which electrical current passes through a concrete sample during a six-hour exposure period (ASTMC 1202-97). The interpretation is that the larger the Coulomb number, or the charge transferred during the test, the greater the permeability of the sample. The more permeable the concrete, the higher the coulombs; the less permeable the concrete, the lower the coulombs. The following formula, based on the trapezoidal rule can be used to calculate the average current flowing through one cell.

$$Q = 900\,(I_0+2I_{30}+2I_{60}+2I_{90}+2I_{120}+\ldots+2I_{300}+2I_{330}+I_{360}) \quad (2)$$

Where, Q = current flowing through one cell (coulombs)
I_0 = Current reading in amperes immediately after voltage is applied, and
I_t = Current reading in amperes at t minutes after voltage is applied

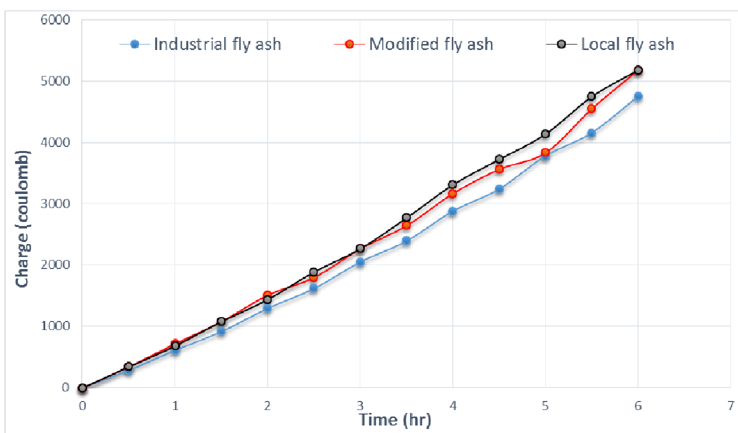

Figure 6: Comparison of Charge passes through the SCC specimen at 7 days.

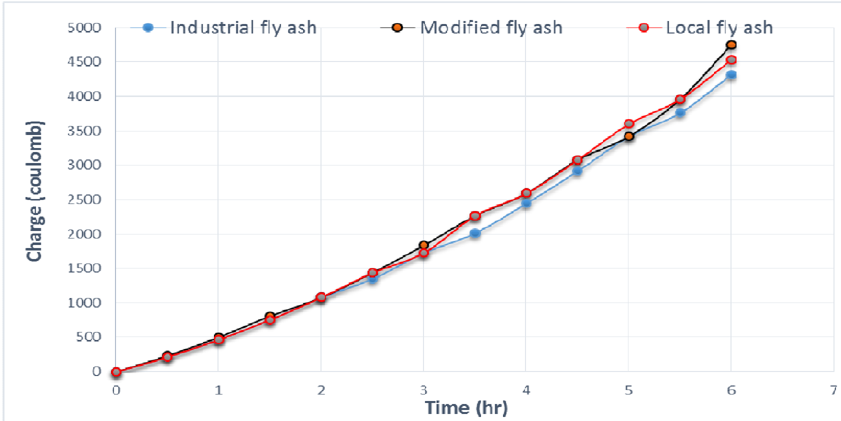

Figure 7: Comparison of Charge passes through the SCC specimen at 28 days.

Rapid chloride permeability test results of SCC mixes made with local, modified local and commercial FA are shown in Fig. 8 at 7 and 28 days.

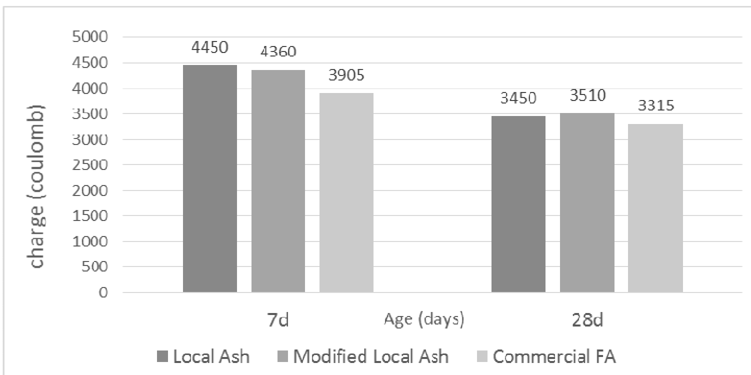

Figure 8: RCPT-Test Results Comparison

Commercial FA results the highest penetration resistance of 3905 and 3315 coulombs charge passed through the concrete specimen curing at 7 and 28 days whereas the Local Ash gives the minimum resistance of 4450 coulombs at the early age of 7 days and modified Local Ash results 3510 coulomb at 28 days. Chloride ion penetration depends on the chloride binding capacity of the constituent materials. Usually chlorides penetrate into concrete by diffusion along water-conveyance paths or open pores. The resistance to such diffusion can be increased by refining the pore-structure of the concrete. From the test result, it has been observed that the total charge passed decreases with the increase in fineness of the fly ash content and the age of concrete in all the mixture proportions. Total charge passed decreases with the increase in fineness of the fly ash content and the age of concrete in all the mixture proportions.

Table 2: Charge passed and rating for SCC mixes for different FA

SCC	7 days		28 days	
	Charge passed (Coulomb)	**Chloride ion permeability**	**Charge passed (Coulomb)**	**Chloride ion permeability**
Local Ash	4446	High	3447	Moderate
Modified Local Ash	4361	High	3510	Moderate
Commercial FA	3906	Moderate	3312	Moderate

The RCPT values (total charge passed in 6 hours) were quite large during the initial 7-days periods. Each point on a table is the average of three test values. Local Ash based SCC mixes evaluated herein have highest RCPT values indicating the minimum resistance to chloride ion penetration which is less than 14% and 4% penetration resistance value than the reference SCC made with commercial FA and can be classified as High and moderate chloride permeability concrete mixes (ASTM C1202–94 assessment criteria) at 7 & 28 days respectively.

Modified Local Ash gives the more satisfactory penetration resistance value than the Local Ash based SCC which is about 12% and 6% at 7 and 28 days respectively which fall in the range of moderate penetration values. This resistance to chloride penetration of concrete was significantly increased due to the incorporation of finer modified Local Ash particles. Such an increase in chloride-ion penetration resulted from the reduced average pore-size of the paste, their filler as well as pozzolanic effects and the improved interfacial zone. This comparative results indicates a promising scope of Local Ash to be used for SCC production.

4. CONCLUSIONS

The present research was restricted to strength development and chloride ion penetration test due to the incorporation of local, modified local and commercial FA in SCC production. The ash collected from integrated MSW power plant and rice mill was coarser than the commercial FA and showed a difference in strength at various ages from reference SCC. The Local Ash based SCC had shown satisfactory strength developments and chloride ion penetration resistance value compared to the reference SCC made with commercial FA. The use of modified Local Ash in SCC influenced the permeability of concrete due to pozzolanic and cementitious reaction that paved the way to a phenomenon of reducing the pore structure in grains.

The following conclusions drawn based on the results of the present study.

- ❖ The incorporation of Local Ash in SCC production has a potential scope of replacing commercial FA for more economical and durable concrete.
- ❖ Compressive strength of SCC made with equivalent Local Ash was more than 90% of the reference SCC made with commercial FA, while the permeability by RCPT was 6% higher in the former.
- ❖ The SCC with Local Ash also passed the other rheological requirements, suggesting a promising scope of Local Ash to be used for SCC production.

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