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THE USE OF BLACK RICE HUSK ASH AS AN ADDITIVE IN HIGH VOLUME FLY ASH SELF CONSOLIDATING CONCRETE

Bui Le Anh Tuan[*1], Chao-Lung Hwang[2], Yuan-Yuan Chen[3], Mewael Gebregirosgis Tesfamariam[4] and Tran Thi Bich Quyen[5]

[*1]Lecturer, Dept. of Civil Engineering, Can Tho University, Viet Nam, Campus II, 3/2 street, Ninh Kieu district, Can Tho city, Vietnam

[2]Professor and Chair, Dept. of Construction Engineering, National Taiwan University of Science and Technology, 43, Keelung Rd., Sec. 4, Taipei 106, Taiwan, R.O.C.

[3]Associate Professor, Dept. of Architecture, Hwa-sha Institute of Technology, 1, Gongjhuan Rd., Zhonghe Dist., New Taipei City, Taiwan, R.O.C.

[4]MSc. Candidate, Dept. of Construction Engineering, National Taiwan University of Science and Technology, 43, Keelung Rd., Sec. 4, Taipei 106, Taiwan, R.O.C.

[5]Lecturer, Dept. of Chemical Engineering, Can Tho University, Viet Nam, Campus II, 3/2 street, Ninh Kieu district, Can Tho city, Vietnam.

ABSTRACT

The possibility of using residual rice husk ash, a by-product of steam boilers, containing high carbon content in high volume fly ash self-consolidating concrete was investigated in this study. The concretes produced were tested for fresh and harden properties, i.e. slump, slump flow, compressive strength, electrical resistivity, ultrasonic pulse velocity, chloride ion penetration and sulfate attack tests. Concretes having slump of 240−250 mm and slump flow of 500−665 mm were achieved without bleeding and segregation. The high volume fly ash self consolidating concrete having 28-day compressive strength of 28.47−44.98 MPa could be obtained with minimum cement content of as low as 152−203 kg/m3, this was done by increasing the mix proportion amount of fly ash and black rice husk ash up to 60% of the total weight of cementitious materials. The results on durability properties evidenced that, the produced concretes could be considered as durable and have good corrosion endurance. Moreover, the concretes found to be sufficient enough to use in reinforced cement concrete construction.

Keywords- *High volume fly ash self-consolidating concrete; Rice husk ash; Compressive Strength; Durability; Waste management.*

I. INTRODUCTION

Fly ash is a by-product of coal powder generation that consists mainly of SiO_2, Al_2O_3, Fe_2O_3 and CaO and some impurities [1]. This is an important ingredient for making high performance concrete (HPC) or self consolidating concrete (SCC). Fly ash with spherical shape improves the workability of fresh concrete [2] due to the ball bearing effect at low addition, and also affects the volume stability of hardened concrete. Using a large amount of fly ash is not helpful in workability without the addition of other chemical admixtures due to its small size and low density, but at proper proportions it is quite helpful to reduce the problem of bleeding and segregation. Besides, previous investigations show that the use of fly ash in concrete results an improvement in the properties of concrete including lower heat of hydration [3], lower permeability and higher corrosion resistance [4], reduces chloride ingress [5] and so on. However, concrete containing fly ash tends to have lower strength development especially at high cement replacement rates [3, 5].

Research on high volume fly ash concrete has been in process at Canada Centre for Mineral and Energy Technology (CANMET) since 1985 [5]. In this type of concrete, the cement content is kept at about 155 kg/m^3, the water-to-cementitious materials ratio is the order of 0.30 and ASTM Class F fly ash varies from 54 to 58% of the total cementitious materials. Finally, this concrete exhibited excellent mechanical and durability properties. Since then, several researchers have advocated the use of not only high volume fly ash but also other pozzolanic materials in both HPC and SCC [1, 6-12]. Generally, the concrete mix techniques in case of supplementary cementitious materials (such as fly ash, blast furnace slag, silica fume, rice husk ash, etc) used can be divided into three main categories [1]. First, additional method involves direct weight addition of supplementary cementitious material to

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cement, and then a part of the aggregate in concrete is replaced in order to achieve correct yield. Second, partial replacement method involves replacement of a part of the cement with excess weight of supplementary cementitious material and a part of the aggregate is also replaced in order to achieve the correct yield. The third method is divided into a modified replacement method and a rational proportioning method. However, a considerable amount of research has been done on concrete, which contains supplementary cementitious materials as partial cement replacement. Most researchers have looked for the optimum amount of supplementary cementitious materials in concrete by the partial replacement method [1, 2, 11]. Kuder et al [9] and Hannesson et al [11] have reported that typical replacement levels used of supplementary cementitious materials in concrete are between 20% and 50% and rarely exceeding 60%. Bouzoubaâ and Lachemi [2] have produced high volume fly ash SCCs having 28-day compressive strength of about 26−48 MPa by replacing up to 60% of Portland cement with class F fly ash.

The use of blend supplementary cementitious materials of fly ash and rice husk ash offers complementary and synergic effects on the properties of concrete [13, 14]. Fly ash compensates the reduction in workability due to the high water demand by rice husk ash. Progressive reaction of SiO_2 in fly ash with $Ca(OH)_2$ contributes to the later-age strength due to less reactive capacity of fly ash. While rice husk ash is highly reactive, it contributes to increasing the early-age strength.

This paper investigated on the production of high volume supplementary cementitious materials (fly ash and rice husk ash) self-consolidating concrete. There are some differences between the current study and others [2, 5, 9-11]. The major difference is that instead of partial replacement of cement, fly ash was used to fill the void of aggregates and hence increase the density of aggregate system. The purpose of such action is to minimize Portland cement required for design properties such as workability, strength, and durability. Additionally, besides to the acting of physical filler, fly ash reacts chemically as an active pozzolanic material. Afterward, rice husk ash was also added as a partial replacement of cement. The strength and durability performance of SCCs were examined. Finally, the results were compared to those obtained with a conventional control concrete.

II. MATERIALS AND EXPERIMENTAL METHODS

Rice husk ash characteristics

The rice husk ash (RHA) used for this study was collected in Vietnam from steam boilers. The X-ray power diffraction (XRD) pattern of RHA, as shown in Figure 1, indicates that it is crystalline RHA. Moreover, the micrographic structure of the RHA has a porous cellular structure and consists of irregular-shaped particles as shown in Figure 2. In order to use this material as better concrete ingredients, it should be ground in to fine powder; therefore, the collected RHA was ground by a ball mill for 1 hour. By this way, the average particle size can be decreased to 18 μm. As the chemical composition of the RHA presented in Table 1, there is a high value of silica content and loss on ignition (presented the amount of residual carbon) can be observed.

Materials used in concretes

ASTM Type I Ordinary Portland cement, Class F fly ash, and RHA were used as cementitious materials. The physical properties and chemical compositions of these materials are given in Table 1. Crushed coarse aggregate (19 mm maximum size, density 2.67 and absorption capacity 1.4%) and natural sand (modulus of fineness 3.0, density 2.65 and absorption capacity 1.2%) were used in this study. And also Type G superplasticizer (SP), having 43% solid content with specific gravity of 1.18, was used to achieve the desired workability for all concrete mixtures. The mixing water was local tap water.

Testing program

The mixture proportions designed by Densified mixture design algorithm (DMDA) and ACI 211.1 are listed in Table 2. DMDA method was developed and has been successfully applied to many projects in Taiwan [15-18]. In DMDA method, the volume of paste amount (V_p) can be estimated by equation: $V_p = V_v + S \times t = nV_v$, where V_p is total volume of paste; V_v is total volume of void; coefficient n should be in the range of 1.1−1.6. It is suggested that various nV_v coefficients should be tried to obtain the required workability. The concrete mixtures in this study were calculated with water-to-binder ratios (w/b) of 0.35, 0.40 and 0.45. For DMDA method, different paste amount values ($1.1V_v$, $1.2V_v$, and $1.3V_v$) were investigated for w/b of 0.40, while that for w/b of 0.35 and 0.45 was only $1.2V_v$. For ACI method, w/b of 0.40 without pozzolanic materials was tested for comparison.

Table 3 shows the relationship between mix design parameters. Theoretically, the paste amount of a concrete is defined as the sum of the amount cement, water, mineral and chemical admixtures [19]. It is observed that for water-to-binder ratio (w/b) of 0.40, increasing the paste amount (n) value leads to lower water-to-cement ratio (w/c). In contrary, the greater paste amount, the higher water-to-all solid materials ratio (w/s) will be. Similarly, the relation between w/c and w/s also proves that an inverse proportionality, the w/c decreases as the w/s increases. In addition, both the fly ash and RHA-to-cementitous materials ratio (P/B) and fly ash-to-cementitous materials ratio (F/B) decrease with an increase of the paste amount. It means that when the less paste amount is used, the more fly ash will be relatively used. In this study, the total pozzolanic materials were used in the range of 52.0−59.6% of the total cementitious materials, while the amount of fly ash was used between 46.7−55.1%. Moreover, RHA was only used at 10% constant replacement of the cement content in all concrete mixes with the range of 4.5−5.3% of the total cementitious materials.

Slump and slump flow spread of concrete specimens were controlled to meet the SCC requirement which is 230−270 mm and 500−700 mm, respectively. The specimens were cured in saturated limewater at the temperature of 23±2^oC. The test programs on harden concrete of axial compressive strength, ultrasonic pulse velocity (UPV) and electrical resistivity were carried out according to ASTM C39, ASTM C597 and four-point Wenner array probe test method respectively at the age of 7, 28, 56 and 91 days; while the chloride ion penetration test was carried out according to ASTM C1202 at the age of 56 days. Additionally, the sulfate attack test was done at the age of 56 days based on the weight loss and concrete surface damage resistance with the following procedure: two specimens of 100×200 mm concrete cylinders were prepared and cured in lime saturated water up to 56 days. At 56-day age, the specimens were exposed to a cyclic wetting and drying. Each cycle was composed of immersion in 5% Na_2SO_4 solution for 1 d, oven drying at 100^oC for 22 h and cooling in air for 2 h. The weights of samples were measured after cooling in air for each cycle and also observe any surface damage on the specimens. This method can be considered as an accelerated method for sulfate attack.

III. RESULTS AND DISCUSSION

Workability of concrete

The workability of concrete is a basic fresh concrete property which helps to maintain at a plastic state that allows the concrete easy to fill all corners of the form. Good workability leads to the formation of a denser and homogenous concrete while the unit weight can be used to identify the densification of concrete. By adding superplasticizer, the binder could well coat the aggregate without sedimentation. And also the aggregate is suspended within the fresh concrete to improve high flow-ability without bleeding and segregation problems.

Slump and slump flow of fresh concretes are shown in Table 4. The initial slump depth and slump flow ranged from 240 mm to 250 mm and 500 mm to 665 mm respectively. As a result, high-slump flowing concretes were achieved without bleeding and segregation. The reason is due to the good packing density of aggregate and proper amount of pozzolanic materials used in concrete mixtures. Moreover, the addition of fly ash plays an important role in filling the voids within aggregate and hence minimizes the required paste amount for lubricating the aggregate particles. Furthermore, the spherical shape of fly ash act as a bearing ball that reduces the friction force within aggregates besides the surface action of SP. Conversely, since a large amount of SP, 3.98 kg/m^3, was used to maintain proper workability for the conventional concrete (A4000), bleeding was observed. And consequently, the qualities of the mixture would become poor and concrete strength decreases. This is because of that bleeding increases weak zones and voids which leads to decrease the bonding force between aggregates and pastes. Therefore, when concrete is loaded, it will slip from the weak interfaces [15]. From this point of view, a less amount of cement paste is adopted in the densified mixture proportion algorithm and the overall mixing water becomes less, as a result this will be the best key solution to decrease the possibility of bleeding and segregation in concrete.

Compressive strength of concrete

Figure 3(a) shows the relationship between testing age and compressive strength of concrete with different w/b ratios. As expected, the lower the w/b ratio is, the higher the compressive strength. The 91-day compressive strength reached 58.12, 53.75 and 42.04 MPa for the corresponding w/b ratio of 0.35, 0.40 and 0.45, respectively.

The development of compressive strength under different paste amount at the same w/b ratio is shown in Figure 3(b). The results show that under the same w/b ratio the concretes with less paste amount and higher w/c ratio led to lower compressive strength at all testing ages. However, the compressive strengths of concrete with paste amount of $1.2V_v$ (n = 1.2) and $1.3V_v$ (n = 1.3) were almost the same. It can be evidenced that the sufficient paste amount for the w/b ratio of 0.40 in this study is around $1.2V_v$. Under the same w/b ratio, the cement paste could achieve the level of good quality if the paste is enough to coat and bind aggregate particles. In addition, the pozzolanic reaction can only occur if there is available calcium hydroxide, a by-product of the hydration reaction [9, 11]. A balance between the cement and pozzolanic materials in order to get a quantification of all the salient binder materials and their role in both hydration and pozzolanic reactions is very important in case of large amount of pozzolanic materials used. This is evident in the case with paste amount of $1.1V_v$ (n = 1.1) at w/b of 0.40. The compressive strength of concrete with paste amount of 1.1Vv was lowest in all cases at all ages. The trend conflicts with other studies [11, 20], which show the concrete with less paste amount leads to lower early-age compressive strength but higher at later-age when pozzolanic materials such as fly ash, slag are used. The reason may be due to a very low cement content (152 kg) and high amount of pozzolanic materials (224 kg) used; therefore, calcium hydroxide from hydration reaction is not enough for pozzolanic reactions of fly ash and rice husk ash even at later ages. However, under sufficient paste amount, the addition of pozzolanic materials as filler of aggregate in concrete is physically not only helpful to promote the packing density of aggregate but also chemically improves the interface transition zone properties through pozzolanic reaction. This reaction converts calcium hydroxide (total amount about 20%) of cement paste to form low density C-S-H gel that will contribute to long-term performance of concrete. Therefore, after 91-day age the compressive strengths of concrete with paste content of 1.2Vv and 1.3Vv were the same. It is because of the slow of pozzolanic reaction which results slow growth of compressive strength of concretes.

Referring to Figure 3(b), by comparing the compressive strength of the SCC based on DMDA method with different paste amount and concrete designed by ACI method (conventional concrete, control concrete) it can be seen that the 7-day compressive strength of all of SCCs designed by DMDA method was less than that of conventional concrete. In comparison at the same paste amount (375 kg/m^3), i.e. D4011 and A4000 mixtures, the compressive strength of D4011 mixture was lower than that of A4000 mixtures up to 28-day age. However, at later ages, its compressive strength exceeded that of the control concrete. The compressive strength at age of 91 days achieved 1.27 times higher than that of the control concrete. The reason could lie in the efficiency of fly ash and rice husk ash reactions which are getting meaningful following the increase of time. The strength comes from packing of aggregate and hydration of both cement and pozzolanic materials especially after 28−56 days.

In this study, at 28 days age it was able to obtain SCCs with 28.47−44.98 MPa compressive strength, the content of cement required was only 152−203 kg/m^3, thus, saving a lot on the cost of cement needed. For example, in the case of SCC with 28-day compressive strength of 40.14 MPa, the amount of total binders used was 399 kg/m^3, while that of cement used was only 177 kg/m^3. Furthermore, with w/b range of 10% difference there is a wide strength variation of 28.47−44.98 MPa at 28 days, but at later-age of 91 days the strength difference becomes decrease to the range of 42.04−55.22 MPa. The reason for the wide strength variation at the early-age is due to the significant amount of cement reduction with more than 50 kg/m^3 and the late reaction of pozolanic materials discussed above. However, it is interesting to see that the 28 days compressive strengths of all SCC mixtures met the requirement of medium compressive strength (27.5−48 MPa) [21, 22]. Therefore, the SCCs are sufficient enough to use in reinforced cement concrete construction.

Electrical resistance of concrete

Electrical resistance is a matter related to the concrete durability since it is a degree of the obstruction of ion migration. There is a linear relationship between electrical resistivity and probability of corrosion in concrete [23]. When the electrical resistance is high, transport of chlorides will be slow and consequently the corrosion rate of reinforcements in concrete will decrease. Therefore, concrete will be more durable and have a longer life cycle [24]. Buenfeld and Newman [25] have suggested that the minimum value beyond which corrosion cannot occur is

20 kΩ.cm. As expected, the trend with regard to the hardening properties of SCC was: the lower the w/b ratio the higher the electrical resistivity as shown in Figure 4(a). This is due to the fact that the volume of the solid/liquid phase with high w/b ratio is smaller and the distance between grains is a little greater. Therefore, it takes a longer time to fill pore space with hydrates of low cement content than that of high cement content.

Based on the same w/b ratio as shown in Figure 4(b), it shows that the higher paste amount (from 1.1Vv to 1.3Vv), the better electrical resistivity would be at early ages. However, long-term growth (after 28 days) for different paste amount has shown that the higher paste amount, the lower electrical resistivity would be. Since large amount of fly ash and rice husk ash used, the pozzolanic reaction was expected not significant in early age, so resistivity was low. The electrical resistance will grow with the concrete age through pozzolanic reaction of fly ash and rice husk ash. Therefore, after 28 days, the electrical resistance of the concrete rose sharply. It can be concluded that the lower the paste amount is the lower corrosion rate of reinforcements in concrete. In addition, the electrical resistivity of all SCCs reached above the suggested value of 20 kΩ.cm. Therefore, the SCCs have good corrosion endurance.

Comparing with the electrical resistivity of concrete achieved by ACI 211.1, it can be seen that at early days (< 28 days) the differences between the electrical resistivity values of concretes designed by DMDA and conventional concrete were negligible. After 28 days, the electrical resistivity of conventional concrete found that significantly lower than that of concretes designed by DMDA. Moreover, the 91-day electrical resistivity of conventional concrete obtained only 20.18 kΩ.cm, while that of concretes designed by DMDA was measured in the range of 77.46−144.74 kΩ.cm.

Ultrasonic Pulse Velocity

As it was expected that the denser the concrete, the higher the Ultrasonic Pulse Velocity (UPV) of concrete [26, 27]. With fixed paste amount, the better quality of the paste (i.e., lower w/b ratio), the less macro- and micro-pores structure, and also the higher UPV result would be obtained as shown in Figure 5(a). The 91-day UPV values of concretes with w/b ratios of 0.35, 0.40 and 0.45 were measured as 4665, 4539 and 4502 m/s, respectively.

In similar manner with electrical resistivity conclusions, the results in Figure 5(b) show that under the condition of the same w/b ratio of 0.40; the less paste amount in the concrete, the higher the UPV result would be at long term ages. The control concrete had higher UPV value than concretes designed by DMDA at all ages. Generally, the sequence of each ingredient of normal weight concrete that could lead to higher values of UPV is coarse aggregate, sand and paste. Therefore, when pozzolanic reaction takes place rapidly at later ages, at the same w/b ratio the concretes with low cement paste content will be mainly occupied by aggregates and consequently they have high values of UPV. It also implies that high paste content will encounter the risk of micro-crack in paste system that is harmful to the durability of hardened concretes. However, the 91-day UPV of all concrete mixtures ranged from 4502−4665 m/s. Whitehurst [28] has classified the concrete as excellent, good, doubtful, poor and very poor for UPV values of 4500 m/s and above, 3500−4500, 3000−3500, 2000−3000, and 2000 m/s, respectively. Therefore, all concretes produced were classified as good as all results of UPV were greater than 3500 m/s.

Chloride-ion penetration

The presence of chloride ions is an important factor accounting for the corrosion of steel. In order to enhance the durability of concrete, the content of harmful chloride ions must be limited [29]. The total charge passed values in 6 h measured by the chloride permeability test for the SCCs at 56 days with different w/b ratios but the same paste amount are presented in Figure 6(a). The results show that the chloride-ion penetration decreased with a decrease in w/b ratios. The results were compared with the chloride ion penetrability limits suggested by ASTM C1202. It can be seen that the total charge passed values of SCCs were less than 1000 Coulombs. Therefore, the concretes can be assessed as "very low" chloride permeability concretes. A higher w/b ratio implies a greater amount of water present in the cement paste. Under this situation, the volume of capillary pores will be bigger and the chloride ion penetration resistance will be reduced [29]. With the addition of pozzolanic materials, the pores will get smaller and fewer, thereby increasing the chloride ion penetration resistance. P. Dinakar et al [8] have investigated that the alumina content has a significant influence on the total charge passed of the concrete. This is due to some of the chlorides can react with cement compounds, mainly tricalcium-aluminates (C_3A), and forming stable chloro complexes. When the excess of chloride is free, this leads to the initiation of corrosion process. The addition of fly ash in the mix results in an increase in the amount of C_3A and the content of calcium silicate hydrate due to higher amount of alumina. Thus, the chloride binding capacity of concrete tends to increase and then less free chloride will be available. It can be seen that the total charge passed decreases as the alumina increases. Therefore, there is a significant reduction of chloride diffusivity of SCCs with high amount fly ash used. This is in line with previous investigations [8, 30].

Figure 6(b) shows the 56-day values of chloride ion penetration of SCCs at the w/b of 0.40 with different paste amount. The results indicate that the lower the paste amount, the higher the chloride ion penetration would be. However, the level of chloride ion penetration for all SCCs remained in a "very low" range of charge spectrum as per ASTM C1202 assessment criteria. Thus, it can concluded that the SCCs containing high amount of fly ash and rice husk ash had a high resistance to the passage of chloride ion. The corresponding conventional concrete without any addition of pozzolanic materials was shown as the value in the "moderate" range according to the assessment criteria. This indicates that the SCC mixtures with high volume fly ash and rice husk ash performed much better with respect to chloride ion penetrability.

Sulfate attack

The mass change could be considered as the best indicator of degree of deterioration due to physical attack in field structure by the laboratory experiment [31, 32]. Mass change results with number of cycles for the various mixtures are shown in Figures 7(a) and (b). The specimens were shown a decrease in mass up to 5 cycles and thereafter continuous increase up to 20 cycles. The rate of mass change increased when increasing w/b ratio (Figure 7a). When paste content increased it can be seen that the weight change values also decreased. The mass changes were almost the same between paste amount values of $1.2V_v$ and $1.3V_v$ as shown in Figure 7(b). However, the mass changes of concrete mixtures were all insignificant up to 20 cycles (< 1.2%). The addition of fly ash and rice husk ash as well as low cement content in the concretes mixtures results in a decreased $Ca(OH)_2$ content in the hydrated cementitious matrix, decreased permeability and more C-S-H gel. Lower permeability and $Ca(OH)_2$ content in the mixtures beneficially affect the performance of specimens in sulfate solution. Mass increase can be explained as flowing reasons [33-36]. The mass increase is due to the filling up of pores by expansive reaction products, resulted in densifying the hardened concrete samples. The results of continuous water absorption, slowly compensating for the chemical shrinkage due to hydration of the cement are also considered to be reason of the increase of weight.

IV. CONCLUSION

This paper investigates fresh and hardened properties of SCC containing high amount of fly ash and ground black rice husk ash (up to 60 % in weight of binder amount). The present investigation has shown that it is possible to use ground black rice husk ash as additive to produce medium strength high volume fly ash self consolidating concrete with cement content as low as 152−203 kg/m^3. The properties of the concretes are summarized as follows:

(1) SCCs having slump depth of 240−250 mm and slump flow of 500−665 mm were achieved without bleeding and segregation.

(2) 28-day compressive strength levels of 28.47−44.98 MPa could be obtained. This meets the requirement of medium compressive strength (27.5−48 MPa). Therefore, the concretes are sufficient enough to use in reinforced cement concrete construction.

(3) Both electrical resistivity and ultrasonic pulse velocity results of the concretes reached above threshold limit values, i.e. 20 kΩ.cm and 3500 m/s, respectively. Therefore, the concrete may be considered to be durable and have good corrosion endurance. All concretes were assessed as "very low" chloride permeability concretes according to ASTM C1202 standard. While the corresponding control concrete without any addition pozzolanic materials was evaluated in the "moderate" range.

The results have also shown that the amount of cement paste and water should be minimized as low as possible in mix design for durable concrete. Under sufficient paste amount, the utilization of high volume fly ash and ground black rice husk ash is helpful to develop the long-term strength and durability of SCC.

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REFERENCES

[1] Oner A, Akyuz S, Yildiz R. An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash in concrete. Cement and Concrete Research. 2005;35(6):1165-71.
[2] Bouzoubaâ N, Lachemi M. Self-compacting concrete incorporating high volumes of class F fly ash: Preliminary results. Cement and Concrete Research. 2001;31(3):413-20.
[3] Atiş CD. Heat evolution of high-volume fly ash concrete. Cement and Concrete Research. 2002;32(5):751-6.
[4] Boğa AR, Topçu İB. Influence of fly ash on corrosion resistance and chloride ion permeability of concrete. Construction and Building Materials. 2012;31(0):258-64.
[5] Malhotra VM. Durability of concrete incorporating high-volume of low-calcium (ASTM Class F) fly ash. Cement and Concrete Composites. 1990;12(4):271-7.
[6] Kayali O, Sharfuddin Ahmed M. Assessment of high volume replacement fly ash concrete – Concept of performance index. Construction and Building Materials. (0).
[7] McCarthy MJ, Dhir RK. Development of high volume fly ash cements for use in concrete construction. Fuel. 2005;84(11):1423-32.
[8] Dinakar P, Babu KG, Santhanam M. Durability properties of high volume fly ash self compacting concretes. Cement and Concrete Composites. 2008;30(10):880-6.
[9] Kuder K, Lehman D, Berman J, Hannesson G, Shogren R. Mechanical properties of self consolidating concrete blended with high volumes of fly ash and slag. Construction and Building Materials. 2012;34(0):285-95.
[10] Khokhar MIA, Roziere E, Turcry P, Grondin F, Loukili A. Mix design of concrete with high content of mineral additions: Optimisation to improve early age strength. Cement and Concrete Composites. 2010;32(5):377-85.
[11] Hannesson G, Kuder K, Shogren R, Lehman D. The influence of high volume of fly ash and slag on the compressive strength of self-consolidating concrete. Construction and Building Materials. 2012;30(0):161-8.
[12] Siddique R. Performance characteristics of high-volume Class F fly ash concrete. Cement and Concrete Research. 2004;34(3):487-93.
[13] Chindaprasirt P, Rukzon S. Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. Construction and Building Materials. 2008;22(8):1601-6.
[14] Isaia GC, Gastaldini ALG, Moraes R. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cement and Concrete Composites. 2003;25(1):69-76.
[15] Hwang CL, Lin JJ, Lee LS, Lin FY. Desified mixture design alogorithm and early properties of high-performance concrete. Journal of the Chinese Institute of Civil and Hydraulic Engineering. 1996;8(2):217-9.
[16] Hwang C-L, Hung M-F. Durability design and performance of self-consolidating lightweight concrete. Construction and Building Materials. 2005;19(8):619-26.
[17] Hwang CL. The Theory and Practice of High Peformance Concrete. 3rd ed. Taipei, Taiwan: Janes' Book Publisher Co.; 2003.
[18] Hwang C-L, Chang P-K, Peng Y-N. Application of High-Performance Concrete to High-Rise Building in Taiwan Advances in Structural Engineering. 2001;4(2):65-73.
[19] Rozière E, Granger S, Turcry P, Loukili A. Influence of paste volume on shrinkage cracking and fracture properties of self-compacting concrete. Cement and Concrete Composites. 2007;29(8):626-36.
[20] Leemann A, Lura P, Loser R. Shrinkage and creep of SCC – The influence of paste volume and binder composition. Construction and Building Materials. 2011;25(5):2283-9.
[21] Su N, Hsu K-C, Chai H-W. A simple mix design method for self-compacting concrete. Cement and Concrete Research. 2001;31(12):1799-807.
[22] Su N, Miao B. A new method for the mix design of medium strength flowing concrete with low cement content. Cement and Concrete Composites. 2003;25(2):215-22.
[23] Polder RB. Critical chloride content for reinforced concrete and its relationship to concrete resistivity. Materials and Corrosion. 2009;60(8):623-30.
[24] Ramezanianpour AA, Pilvar A, Mahdikhani M, Moodi F. Practical evaluation of relationship between concrete resistivity, water penetration, rapid chloride penetration and compressive strength. Construction and Building Materials. 2011;25(5):2472-9.
[25] Buenfeld NR, Newman JB, Page CL. The resistivity of mortars immersed in sea-water. Cement and Concrete Research. 1986;16(4):511-24.
[26] Hwang CL, Chen YY. Evaluation of Compressive Strength of High Performance Concrete by Ultrasonic Pulse Velocity. Journal of the Chinese Institute of Civil and Hydraulic Engineering. 1998;10(3):591-4.
[27] Malhotra VM. Testing Hardened Concrete: Nondestructure Methods. American Concrete Institute Monograph Series; 1976.

[28] Whitehurst EA. Soniscope tests concrete structures. Bulletin (Portland Cement Association Research and Development Laboratories Research Dept) ;. [Portland Cement Association: Chicago; 1951.
[29] Hou W-M, Chang P-K, Hwang C-L. A study on anticorrosion effect in high-performance concrete by the pozzolanic reaction of slag. Cement and Concrete Research. 2004;34(4):615-22.
[30] Zhu W, Bartos PJM. Permeation properties of self-compacting concrete. Cement and Concrete Research. 2003;33(6):921-6.
[31] Al-Dulaijan SU. Sulfate resistance of plain and blended cements exposed to magnesium sulfate solutions. Construction and Building Materials. 2007;21(8):1792-802.
[32] Aye T, Oguchi CT. Resistance of plain and blended cement mortars exposed to severe sulfate attacks. Construction and Building Materials. 2011;25(6):2988-96.
[33] Sumer M. Compressive strength and sulfate resistance properties of concretes containing Class F and Class C fly ashes. Construction and Building Materials. 2012;34(0):531-6.
[34] Rozière E, Loukili A, El Hachem R, Grondin F. Durability of concrete exposed to leaching and external sulphate attacks. Cement and Concrete Research. 2009;39(12):1188-98.
[35] Lee S-T. Influence of recycled fine aggregates on the resistance of mortars to magnesium sulfate attack. Waste Management. 2009;29(8):2385-91.
[36] Persson B. Sulphate resistance of self-compacting concrete. Cement and Concrete Research. 2003;33(12):1933-8.

Table 1 Physical and chemical analysis of cement, RHA and fly ash.

	Item	Cement	RHA	Fly ash
Physical properties	Specific gravity	3.15	2.06	2.17
Chemical compositions (%)				
	SiO_2	22	91	60.58
	Al_2O_3	5.6	0.35	18.54
	Fe_2O_3	3.4	0.41	11.39
	CaO	62.8	--	5.24
	MgO	2.6	0.81	1.67
	SO_3	2.1	1.21	0.58
	P_2O_5	--	0.98	--
	Na_2O	0.4	0.08	0.51
	K_2O	0.8	3.21	1.23
	Loss on ignition	0.51	8.5	--

ISSN 2348 – 8034
Impact Factor- 3.155

Table 2. Mixture proportions of SCCs

Mix no.	w/b	V_p	Mix proportion (kg/m^3)						
			Stone	Sand	Cement	Fly ash	RHA	Water	SP
D3512	0.35	1.2V_v	799	1017	203	202	23	170	3.38
D4011	0.40	1.1V_v	818	1041	152	207	17	171	3.30
D4012	0.40	1.2V_v	799	1017	177	202	20	180	3.07
D4013	0.40	1.3V_v	779	992	203	197	23	189	2.57
D4512	0.45	1.2V_v	799	1017	154	202	17	189	2.50
A4000	0.40	-	829	1018	375	-	-	150	3.98

Table 3. Relationship among the parameters of mixture proportions.

Mix no.	V_p	w/b	w/c	w/s, %	P/B, %	F/B, %	R/B, %	R/(C+R), %	Paste amount (m^3/m^3)
D3512	1.2V_v	0.35	0.74	6.67	52.5	47.2	5.3	10.0	0.344
D4011	1.1V_v	0.40	0.99	6.72	59.6	55.1	4.5	10.0	0.318
D4012	1.2V_v	0.40	0.90	7.20	55.6	50.6	4.9	10.0	0.334
D4013	1.3V_v	0.40	0.83	7.69	52.0	46.7	5.3	10.0	0.350
D4512	1.2V_v	0.45	1.09	7.67	58.7	54.1	4.6	10.0	0.334
A4000	-	0.40	0.40	7.00	-	-	-	-	0.292

w/s = (weight of water)/(the sum of the amount of all solid materials); P/B = (weight of fly ash and RHA)/(total weight of cementitous materials); F/B = (weight of fly ash)/(total weight of cementitous materials); R/B = (weight of rice husk ash)/(total weight of cementitous materials); R/(C+R) = (weight of rice husk ash)/(total weight of rice husk ash and cement).

Table 4. Workability of SCCs.

Mix no.	w/b	V_p	Slump (mm)	Slump flow (mm)	Flow time (s)
D3512	0.35	$1.2V_v$	245	665	29
D4011	0.40	$1.1V_v$	250	650	41
D4012	0.40	$1.2V_v$	250	515	19
D4013	0.40	$1.3V_v$	245	550	18
D4512	0.45	$1.2V_v$	240	560	20
A4000	0.40	--	245	500	25

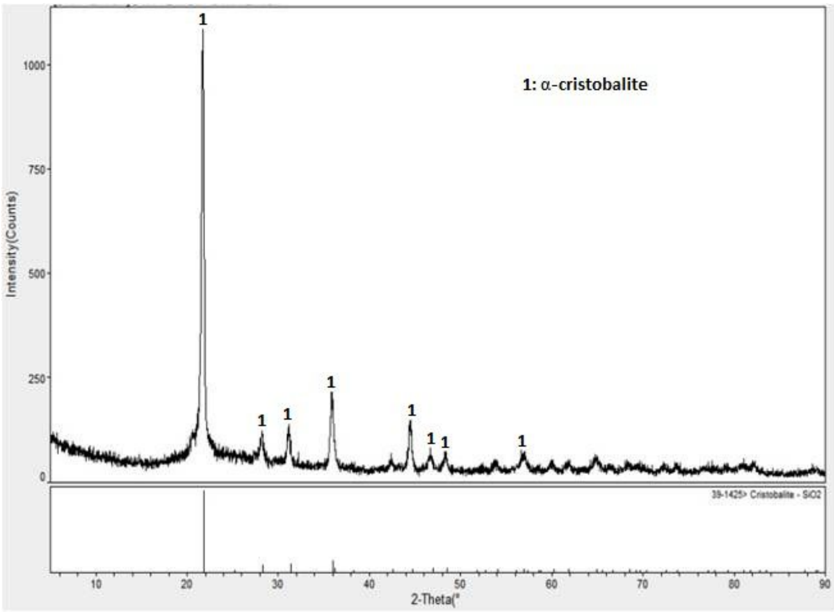

Figure 1. XRD patterns of rice husk ash

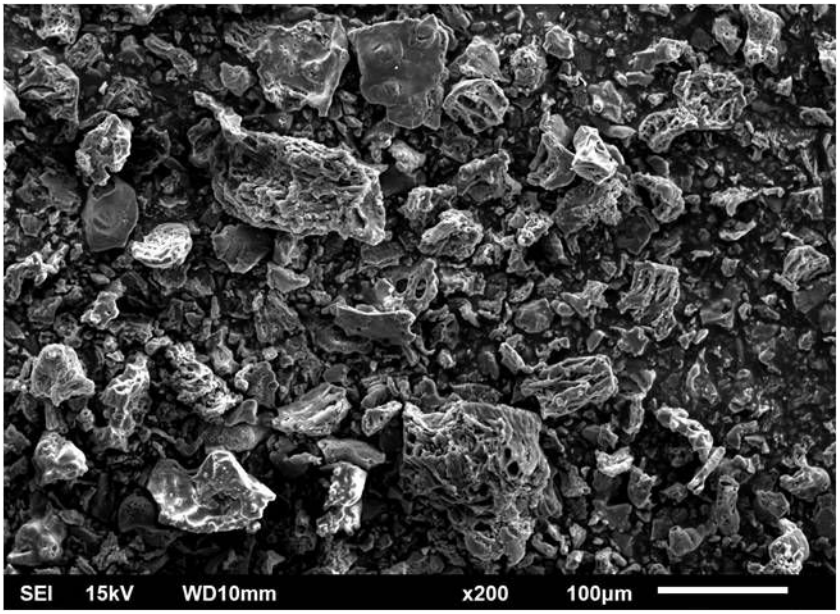

Figure 2 SEM micrographs of rice husk ash

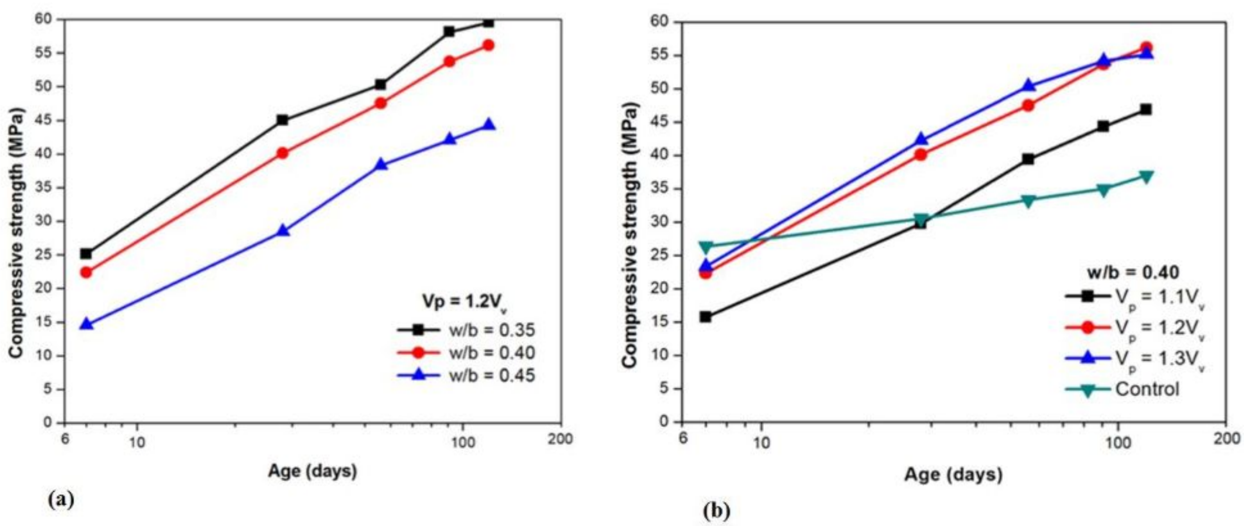

Figure 3. Strength development of SCCs with: (a) different w/b ratios; (b) different paste amount

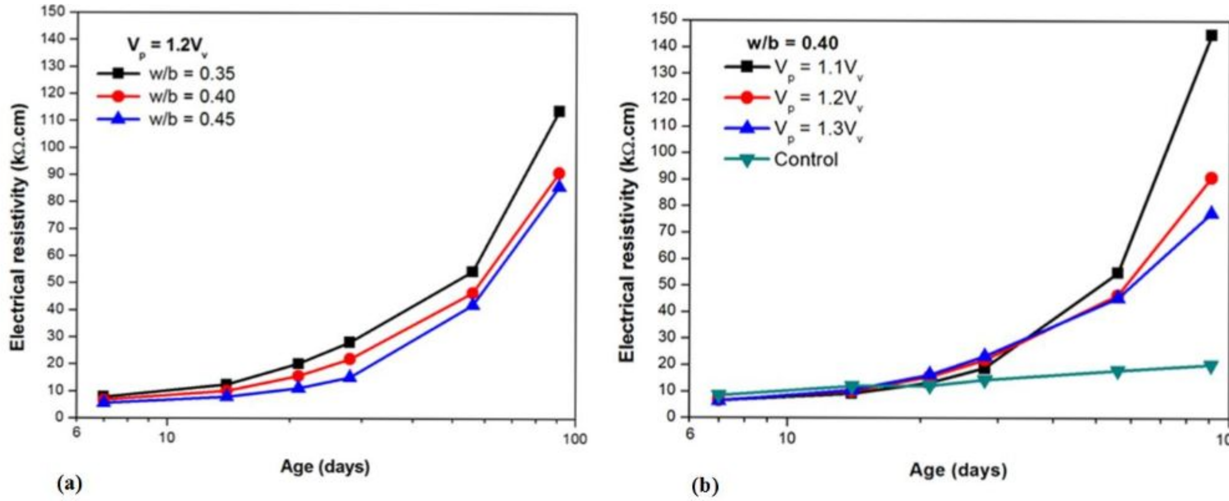

Figure 4. Electrical resistivity of SCCs with: (a) different w/b ratios; (b) different paste amount

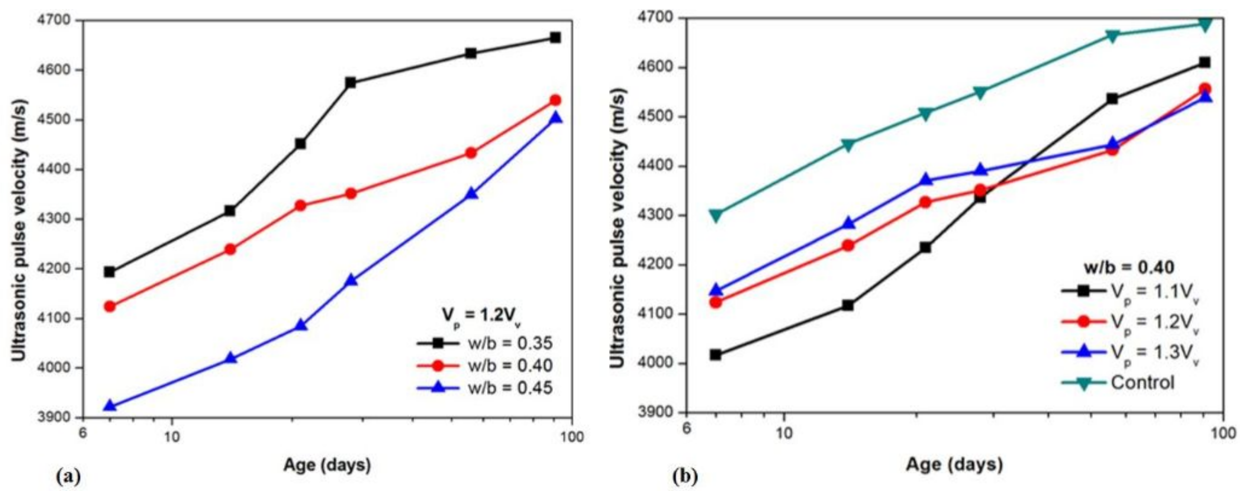

Figure 5. Ultrasonic pulse velocity of SCCs with: (a) different w/b ratios; (b) different paste amount

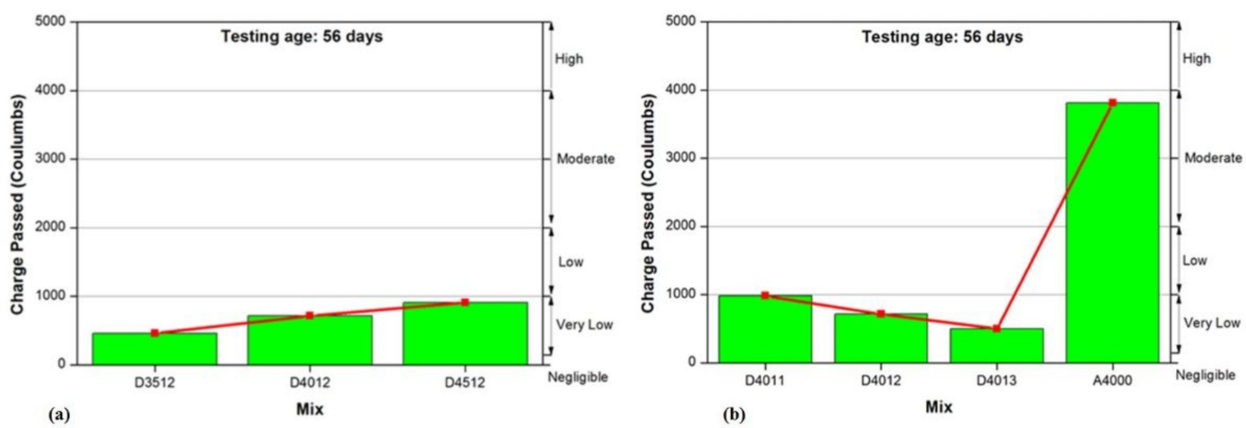

Figure 6. Chloride-ion penetration of SCCs with: (a) different w/b ratios; (b) different paste amount

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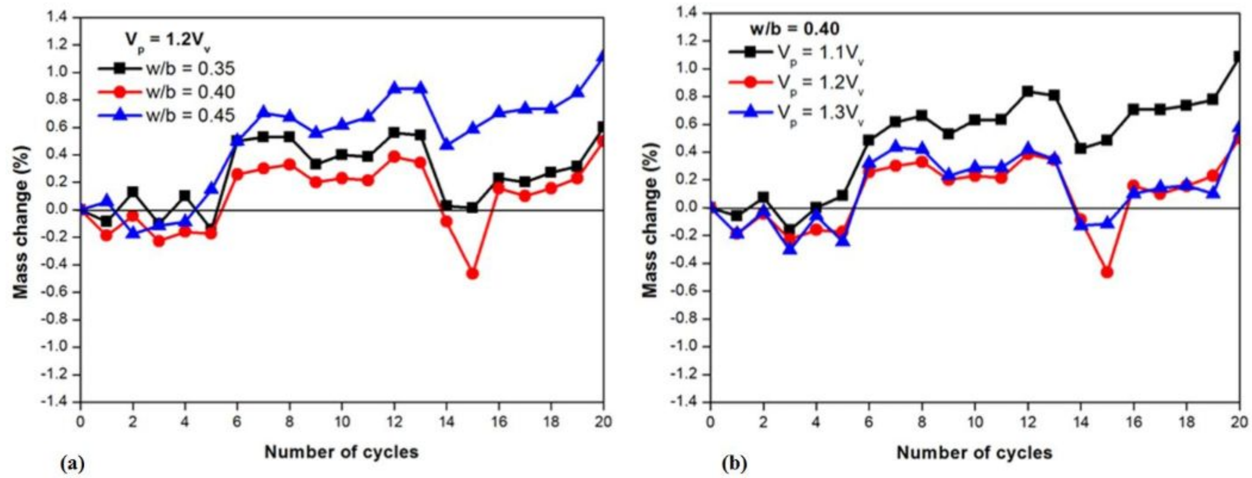

Figure 7. Mass change of SCCs with: (a) different w/b ratios; (b) different paste amount