

Overview of the Influence of Burning Temperature and Grinding Time to the Properties of Cementitious Material based Agricultural Waste Products

Adrina Rosseira^{1,*}, Noor Nabilah Sarbini², Izni Syahrizal Ibrahim², Nor Hasanah Abdul Shukor Lim², Abdul Rahman Mohd Sam² and Nur Fatin Nazira Ab.Karim²

¹ Faculty of Civil Engineering, Universiti Teknologi MARA Pasir Gudang, 81750 Johor, Malaysia.

² Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.

* Corresponding author: adrina9587@johor.uitm.edu.my

Abstract. Utilisation of waste product as a construction material is received encouraging response worldwide. “Waste to wealth” has hit of waste reused that in line with Malaysia Green Technology Master Plan 2017-2030, that promoted on green and sustainable concept in a construction industry. Cement is widely used as a construction material due to its excellent binding properties. Nevertheless, two important facts on cement as a material that lacks of green and sustainable are on its production and compositions. Cement production lead to the depletion of natural resources and extremely pollute the environmental due to the carbon dioxide emissions. Thus, any sustainable products that can serve as like the binder material are a good replacement to cement material. The agricultural sector is one of the sources of a waste product. Typical disposal methods are by burning process or decomposed to the landfill due to its simple in operation lead to the environmental issues. Previous studies found on the use of few agricultural wastes as a cement replacement such as palm oil fuel ash (POFA), sugar cane bagasse ash (SCBA) and rice husk ash (RHA). Thus, this paper is discussed on the review of a previous researches on the agricultural waste as a supplementary cementitious material (SCM) that focused on the physical and chemical properties due the effect of burning temperature and particle size distribution. This review found that the suitable temperature for burning is within the range of 500-700°C and grinding effect is within 90-120 minutes to produce a better result for pozzolanic index. The suggested burning time is not more than 5 hours in order to consider the cost and economic value of the burning production. This will assist future researches on to what extent of temperature and particle size from agricultural waste material to develop SCM.



1. Introduction

Nowadays, agricultural waste is a valuable material that can be utilise in many new and innovative ways. Many researchers have used their creativity and innovation to transform an unwanted product such as agricultural waste into wealth. In the construction industry, cement is one of the main important materials that are used to produce concrete and mortar. In conjunction with the concept of sustainable development, supplementary cementitious materials, also known as pozzolanic materials have been introduced in order to reduce the cement proportion in the mix. There have been many attempts by researchers to use pozzolanic material from agricultural waste as a supplementary cementitious material (SCM). The application of concrete and mortar by using SCM from agricultural waste offers an opportunity in practicing sustainable development and will translate to economic benefits if practiced on a global scale [3-5]. Currently, there have been many studies on Rice Husk Ash (RHA), Palm Oil Fuel Ash (POFA), and Sugar Cane Bagasse Ash (SCBA) due to the easy availability of this kind of waste from the agricultural sector. Previous studies have shown that rice husk ash, bagasse ash, and palm oil fuel ash have good pozzolanic properties [14-16, 20-23]. The previous researchers found that there are some factors that influence the pozzolanic activity of the ashes produced such as the burning temperature, chemical composition, amorphous and crystalline composition and the particle size [13-14,21,28,31]. Too high a burning temperature tends to produce more carbon within the ashes and lead to the crystallisation [17]. There have been many studies conducted on the potential of the pozzolanic material from agricultural waste in the production of mortar or concrete. However, there is still a lack of investigation on the influence of burning temperature and grinding time to the pozzolanic activity. Thus, this paper intent to discussed the influence of burning temperature and grinding time to the physical and chemical properties of agricultural waste materials focused to RHA, POFA and SCBA.

2. Background of Supplementary Cementitious Material

Pozzolanic material is a supplementary cementitious material (SCM), and among the alternative as a binder material. SCM composed of siliceous formation from the burning process with the total percentage of silica oxide, alumina oxide and iron oxide ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) of more than 70%. Loss of ignition (LOI) must be less than 10% for mineral admixture class N and also less than 6% for class F and C [1]. At room temperature, SiO_2 and Al_2O_3 in glassy phase contained in agricultural waste ash can react with $\text{Ca}(\text{OH})_2$ as pozzolanic materials to form calcium silicate hydrate or calcium aluminates hydrate [10]. The higher value of silica oxide (SiO_2) tend to increase the ash effectiveness while alumina can contribute to the pozzolanic effect of silica [4,29]. Somehow, the chemical composition may vary according to the origin of the ashes that have been used [26]. The chemical composition and physical composition of the ashes produced for replacing cement are influenced by many factors. The geographical factors, the preparation of the samples, year of harvest and type of equipment used affect the composition of the ashes products from agricultural wastes [32]. It is believed that these factors play a significant role in the production of a pozzolanic material. Burnt ash produced from the mill is known as a raw ash, and ash that is produced by burning under controlled temperature is better than that under uncontrolled temperature. Burning the ash under controlled temperature and grinding are parts of the process in the treatment of the ash. Grinding can control the particle size distribution and increase the specific area of the ash produced [17,19-22]. The pozzolanic activity of the ash produced can be improved by decreasing the pozzolanic particle size. This will lead to the increment of the amount of amorphous silica in the ash where it is important to produce pozzolanic activity [27, 31].

2.1. Rice Husk Ash

Rice husk ash that globally produced have been estimated approximately more than 7.5% million ton per annum [5]. Current practice for managing this waste includes utilizing it as a fuel boiler [9,13]. Rice husk ash (RHA) is an ash that is produced from the boiler fuel that is used to generate electricity. About 25% of the rice husk from the boiler will be converted to RHA where there is no significant commercial value that can be added and end up as a waste. Researchers have found that RHA

contains a high amount of silica oxide (SiO_2), which has a big potential to be used as a pozzolanic material [24, 32].

2.1.1. Burning Temperature of RHA

Chindaprasirt P. et al (2008) and Bie R.S et al. (2015) found that burning under controlled temperature is one key factor that influences the reactivity and strength of RHA produced [7,17]. The amorphous form of RHA is retained under controlled burning temperature at 700°C. Table 1.0, shows the range of burning temperature and duration used in some of the studies[35]. They studied the different burning temperature of 550°C, 600°C, 650°C, 700°C, 750°C and 1100°C for different burning durations. They found that RHA burnt at 650°C within 1 hour produced non-crystallisation RHA and fulfills the requirement of ASTM standard C618-03. The strength of RHA concrete with 7%, 10% and 15% RHA replacement was higher than the plain normal concrete. According to Bie R.S. et al (2015), they used to burn RHA at 600°C (1h and 2h) and 700°C (1h). RHA burnt at 600°C within 2h chosen as the suitable burning temperature due to the higher pozzolanic index and its amorphous and lower LOI value that lead to the significant removal of the carbon particles in the ashes. The increase of the specific surface area of the RHA is due to the decrease in the size particle of RHA (0.1-100nm). The decrease of potassium content in the RHA was found to give a significant influence to the increase of specific surface area. The mechanical properties testing proved that the RHA has a big potential to be used as a pozzolanic material with 10% of RHA replacement in the mortar. The residual carbon that is found in RHA at 700°C indicates that a higher temperature is not suitable to burn the fibrous unburnt particle in RHA. Moreover, too high a burning temperature leads to the formation of crystallisation [9,35]. In other study by Hadipramana J. et al (2016), raw RHA that was burnt under uncontrolled temperature of between 700°C and 800°C be categorized as a pozzolanic material based on the pozzolanic index. However, the result from this raw RHA was lower than amorphous RHA from the previous researchers due to the crystalline formation in this type of RHA. There is crystalline particle in the ashes up, to 26.7% and the result from XRD classifies it as crystalline. The result shows that this raw RHA can be categorized as pozzolanic, and the controlled burning temperature is much recommended to produce a better strength and pozzolanic index in the mortar or concrete application.

Table 1.0 Chemical composition of RHA with different burning temperature by previous researchers

Authors	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	LOI
Ramezaniapour <i>et al</i> (2009)	89.61	0.04	0.22	0.91	0.07	1.58	0.42	5.91
Bie R.S <i>et al</i> (2015)	93.0	0.10	0.07	0.92	-	3.62	0.45	1.48
Hadipramana J. <i>et al</i> (2016)	89.90	0.46	0.47	2.02	-	4.50	0.79	-

2.1.2 Grinding of RHA

The decrease in the particle size of the pozzolanic material will tend to increase the amount of amorphous silica and thus improve the pozzolanic activity [25,28]. The smaller particle size of RHA leads to the increase in specific area that contributes to the high consumption of calcium hydroxide and silica of RHA and thus helps to produce a better mechanical strength of concrete [25]. Table 2.0 shows the effect of grinding on the chemical composition of RHA. Ramadhansyah, P.J. et al (2012) studied the influence of different grinding times on the pozzolanic index of RHA. Seven (7) different grinding times, 30mins, 60mins, 90mins, 120mins, 180mins, 240mins and 300mins were selected. The results show that the RHA ground for 90mins created the highest pozzolanic activity index and the compressive strength of concrete at 28 days was almost 40% higher than that of concrete using unground RHA. The increment of grinding time for more than 90mins led to the decrease in the pozzolanic activity index due to the high specific surface of RHA [25]. The researchers used the ground RHA and divided it into two different sizes; small-size (SRHA)(about 3-7% of weight of material retained on a sieve pan size of 45µm) and large-size (LRHA) (about 32-36% of weight of

material retained on a sieve pan size of 45 μ m). Both sizes of RHA were classified as pozzolanic based on their compositions. In terms of compressive strength, the early strength of SRHA mortar was better than LRHA mortar and SHRA mortar showed a continuous strength increment at 7, 14 and 28 days [25]. LRHA mortar strength was lower than the control mortar at all curing days due to the size of the ashes. The finer size of SRHA filled the mortar void effectively which led to the greater pozzolanic reaction. This result shows that the grinding factor plays an important role in producing a pozzolanic material that can be used in mortar or concrete [25,33,41].

Table 2.0 Chemical composition of RHA with grinding by previous researchers

Authors	Grinding time (minutes)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O	MgO	LOI
Ramadhansyah P.J. <i>et al</i> (2012)	90	60.96	0.09	0.09	5.97	0.70	9.02	8.65	5.70
Jamil M. <i>et al</i> (2016) Small-size SRHA	60	89.91	0.13	0.95	0.76	0.01	2.75	0.30	2.99
Jamil M. <i>et al</i> (2016) Large-size LRHA	60	90.21	0.15	0.91	0.72	0.01	2.61	0.10	2.80

2.2. Sugar Cane Bagasse Ash

Malaysia is one of the sugar cane producers, other than India, Philippines, Indonesia and India [5,17,32,37]. Sugarcane Bagasse Ash (SCBA) is the waste product that comes from the sugar industry. After the crushing process for the juice extraction, the waste that is left is known as bagasse. In current practice, the bagasse is utilized as cogeneration boiler. The residue left after the burning process in the boiler is known as bagasse ash [8]. The combustion of sugar cane bagasse in the burning process will produce sugar cane bagasse ash. This valuable waste has been found to be useful as an alternative pozzolanic material in the production of mortar and concrete [7-8]. Uncontrolled burning temperature which is above 800°C and/or too long a period taken to burn the ash will lead to the transition of amorphous silica to the crystallisation [8,19]. Besides, sand from the SCBA that was harvested along with it will lead to the crystallization of silica [19-21].

2.2.1 Burning Temperature of SCBA

Burning at a controlled temperature tends to improve the SCBA properties [42]. Soares *et al* (2014) found that 600°C was the suitable burning temperature to produce SCBA with low carbon content, higher specific area and good amorphous silica where it complies with the considerable criteria for pozzolanic index [17]. They found that too high of a burning temperature leads to the recrystallization of the SiO₂. This is found to be consistent with the previous finding where the burning temperature influenced the pozzolanic reactivity, mineralogical composition and morphology of SCBA [33]. They reported that the morphologies of SCBA that burned at 800°C and 1000°C depend on the composition of Ca (calcium) or Si (silica) content. Based on Table 3.0, this finding showed that the higher the burning temperature was not promising the increase of the siliceous formation. In terms of cost, burning at high temperature will increase the cost. Thus, the suitable burning temperature for SCBA is lower than 800°C and the pozzolanic characteristic can be improved by the grinding process. This is because the selective grinding will lead to the decrease in the quartz and crystallisation formed in the SCBA and thus increase the SCBA pozzolanic activity [20]. Besides, based on the result, it can be concluded that the higher burning temperature will successfully remove the carbon from the ash produced where the loss of ignition decreased with the increase in burning temperature [42]. Incomplete burning of the ash tends to increase the value of loss ignition due to the presence of fibrous particles in the ashes. But, too high of burning temperature will tend to cause recrystallization of the SiO₂. The particle size of the ash increased with the formation of an agglomeration of the ash if burning temperature is too high. Riberio D.V. *et al* (2014) found the strength activity index of burnt SCBA at 600°C and 700°C with 10% of replacement onto the cement showed better mechanical properties than the control mortar.

Table 3.0 Chemical composition of SCBA by previous researchers

Authors	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O	MgO	LOI
Cordeiro (2009)	60.96	0.09	0.09	5.97	0.70	9.02	8.65	5.70
Morales E.V. (2009)	58.61	7.32	9.45	12.56	0.92	3.22	2.04	2.73
Morales E.V. (2009)	59.35	7.55	9.83	12.89	0.96	3.41	2.10	0.81
Minas (2014)	74.47	4.43	6.78	3.24	0.2	5.67	1.27	2.27

2.2.2 Grinding of SCBA

The grinding process in the ash production affect the pozzolanic activity of the ash produced [7-8,19-20]. In the previous studies, some of the collected SCBA came from cogeneration boiler sources and was then burned at a controlled burning temperature in order to produce the amorphous silica or any pozzolanic composition and to remove any carbon or fibrous particles [7]. Bahurudeen A. *et al* (2015) stated that the pozzolanic activity can be improved by using different methods of processing, including the grinding method. They used two different methods of grinding. Firstly, they ground the sieved raw ash (passing through 300 μ m) to different sizes from 210 μ m to 45 μ m fineness. The pozzolanic activity was existed on raw SCBA that was ground to below 53 μ m of sieve pan size [1]. In the second method, they ground the sieved burnt ashes (passing through 300 μ m) and used to burn at controlled burning temperature samples to the cement fineness (300m²/kg). They found that using 700°C of burning temperature and ground up to 120 minutes was suitable to produce the highest pozzolanic activity. This shown by SCBA with strength activity index increment from 72% to 90% at 7 and 28 days, respectively as shown Figure 1.0.

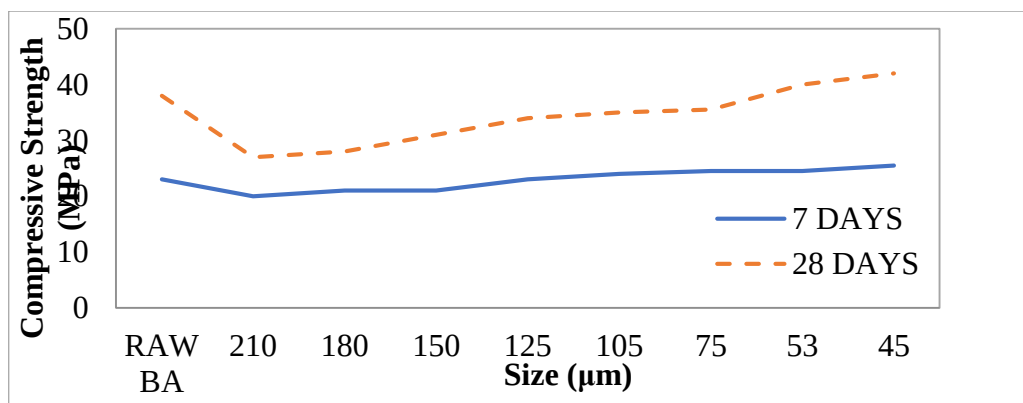


Figure 1. The relationship between SCBA particle of size and compressive strength at 7 and 28 days (Bahurudeen M. *et al*, 2015)

Figure 1.0 showed the relationship between SCBA particle of size and compressive strength at 7 and 28 days [7]. From the graph, it found that the compressive strength of the most ground bagasse ash samples were lesser than the raw bagasse ash. The raw bagasse ash that passing through 300 μ m showed the higher strength compared to the ground bagasse ash of 210 μ m, 180 μ m, 150 μ m, 125 μ m, 105 μ m and 75 μ m at 28 days. SCBA with 53 μ m showed the optimum and sufficient reactivity at 7 and 28 days. Thus, this result can support the future researchers that the increase of particle size and specific area cannot be used as an indication to produce better strength.

2.3. Palm Oil Fuel Ash

The increase of palm oil in the agricultural production leads to the increase of palm oil fuel ash (POFA) as waste materials [27]. Malaysia is one the largest producers of palm oil and produced about 41% from the world statistic [3,16,27,39]. Palm oil waste comes with 20 tons of nut shells, 7 tons fibres and 25 tons of empty bunches were discharged from the mill annually [3]. These wastes are used as a fuel in the palm oil mills. About 5% of POFA are produced from the combustion for the boiler purposes [10]. In current practise of managing POFA waste, it was used as a backfilling, fertiliser and mostly disposed to the landfills, leading to the increase in the landfill areas and causing environmental problems [27]. The high value of LOI will result in an increase in water requirement. Thus, the increased of burning temperature with burning time will increased the percentage of formed oxides and decrease the value of LOI where it removed the carbon content in the ash produced [3]. Chadara C. (2010) concluded that the best temperature to burn the samples within the LOI specification is at of temperature of 800°C (more than 4.5h) and 1000°C (more than 2h). They found that the ground POFA that is burnt at 500°C within 1h contributes to lower LOI and causes an increase in the total siliceous oxides compared to original POFA that produced from boiler combustion. These two different types of POFA showed that there are no significant changes in the mean particle sizes on both types of POFA where ground POFA and unburnt ground POFA were 22.53µm and 22.52µm, respectively. However, the original POFA still need to be sieved and ground in order to remove any unburnt carbon particle from the ash. In terms of compressive strength, 20% of POFA replacement mortar shows a strength improvement than the minimum requirement in ASTM C618-059 [1]. Unground palm oil waste was not sufficient to remove all the carbon content and thus may lead to crystallisation [3]. The grinding method used to reduce particle size of the ash and improve the reactivity of the POFA as a pozzolanic material [3,27]. The grinding was more effective in the POFA that was burnt at higher temperature in order to produce smaller particles size without agglomeration and better strength. Besides, the grinding can speed up pozzolanic activity in the mortar due to the higher specific area and smaller particle size.

2.3.1. Grinding and Burning of POFA

Altair N.M. *et al* (2012) studied the pozzolanic characteristic of ground palm oil waste ash (GPOWA) and treatment palm oil fuel ash (TGPOFA) as shown in Figure 2.0. They used to burn GPOWA at 1000°C and 800°C for 2h and 6h respectively. For TGPOFA, it has been treated by heating at 450°C.

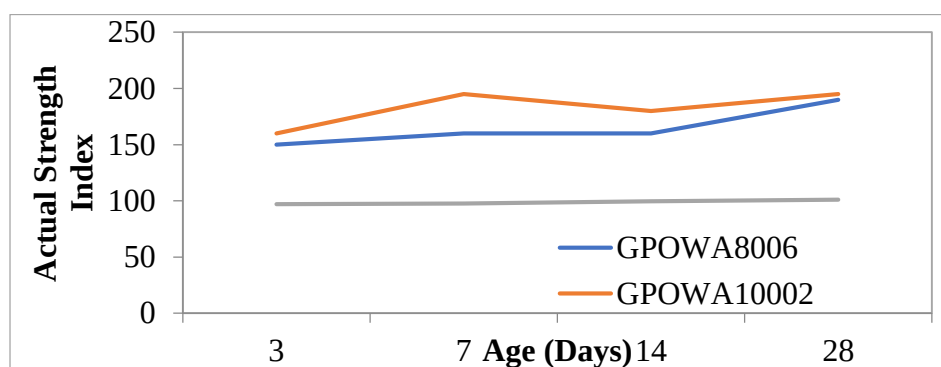


Figure 2. The relationship between different types of palm oil fuel ash and curing days to the activity strength index (Altair *et al*, 2012)

It can be observed that the TGPOFA have been achieved the minimum requirement of 75% at all days [1]. The activity strength index of GPOWA10002 was higher than GPOWA8006 due to its greater amorphous content produced. For the comparison for each type of material used, the strength of GPOWA was higher than TGPOFA at all curing days. This is due to the chemical properties and particle size of GPOWA was greater than TGPOFA where the total main oxides of GPOWA8006, GPOWA10002 and TGPOFA samples were 82.30%, 83.40% and 79.07% while for the average of size particles were 0.29µm, 0.3µm and 2.99µm respectively.

3. Conclusion

Based on the review on the burning temperature and grinding effect to the POFA, RHA and SCBA, there are several key points that can be concluded in terms of burning temperature and grinding time effect to the ash produced. The method of processing of the ashes influences the pozzolanic activity index. The ashes produced may originally be collected at the cogeneration boiler or originally from raw waste and need to be processed at a controlled burning temperature, ground and sieved. The decrease of LOI value is not only provide better workability, it is important to remove all the fibrous unburnt particle in order to obtain the maximum pozzolanic index of the ashes produced. Sieving the raw ashes is recommended in order to remove the coarse particle and carbon from the ashes. Grinding the ashes produced from uncontrolled and controlled burning temperature is needed to ensure the consistency of the pozzolanic index in the mortar or concrete. This is because the grinding will produce a smaller size particle where it can help to increase the strength of the mortar or concrete. The recommended size particle for the pozzolanic ash to be used is below 45µm. This is due to cement fineness itself where it can ease the mix between pozzolanic material. Thus, it can improve the filler effect and pozzolanic reactivity to the sample produced. Time duration is one of the important factors in the burning and grinding processes. Burning the pozzolanic ash at controlled temperature is crucial in order to completely remove the carbon particle and obtain better total main oxides. The time duration for both processes influence the chemical composition and pozzolanic index. Thus, the longer time taken for the processing is questionable as it affects the cost of the ash production at controlled burning temperature and grinding. In view of the current aim of the green construction concept, the use of ash that come from the boiler may reduce the cost of the cement production and helps to sustain the environment and natural resources, reduce the pollution due to current practise of open burning and helps to reduce the waste by transformation of the waste to wealth. But, to ensure better strength and sustainability in mortar or concrete, the ash need to be treated by grinding and burning as proven in this literature review. The reuse of agro-based waste or agricultural waste is crucial to develop sustainable construction industry and environment as to keep and maintain the Earth for future generation use.

Acknowledgement

This research work is funded by the Fundamental Research Grant Scheme for Vot. No. 4F939.

References

- [1] ASTM standard C618-03
- [2] American Society for Testing and Materials (ASTM) C618-12a. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete; 2012
- [3] Altwair, N., Johari, M., Zeyad, A. and Hashim, S. (2012). Pozzolanic characteristics of palm oil waste ash (POWA) and treated palm oil fuel ash (TPOFA). In *Advances in Civil Engineering and Building Materials*. pp.145–149.
- [4] Altwair, N.M., Johari, M.A.M. and Hashim, S.F.S. (2011). Influence of Calcination Temperature on Characteristics and Pozzolanic Activity of palm oil waste ash. *Australian Journal of Basic and Applied Sciences*. 5(11), 1010–1018
- [5] Aprianti S, E. (2017). A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production – a review part II. *Journal of Cleaner Production*. 142, 4178–4194
- [6] Awal, A. S. M. and Hussin, M.W. (2011). Effect of palm oil fuel ash in controlling heat of hydration of concrete. *Procedia Engineering*, 14, 2650-2657.
- [7] Bahurudeen A, and Santhanam M. (2015). Influence of Different Processing Methods on the Pozzolanic Performance of Sugarcane Bagasse Ash.

- [8] Bahurudeen, A, Kanraj, D., Gokul Dev, V. and Santhanam, M.(2015) Performance evaluation of sugarcane bagasse ash blended cement in concrete, *Cem. Concr. Compos.* 59 (2015) 77–88
- [9] Bie, R.S., Song, X.F., Liu, Q.Q., Ji, X.Y. and Chen, P. (2015). Studies on effects of burning conditions and rice husk ash (RHA) blending amount on the mechanical behavior of cement. *Cement and Concrete Composites.* 55, 162–168
- [10] Chandrasekhar S, Pramada PN, Raghavan P, Satyanarayana KG. Microsilica from rice husk as a possible substitute for condensed silica fume for high performance concrete. *J Mater Sci Lett* 2002;21:1245–7
- [11] Chandara, C., Azizli, K.A.M., Ahmad, Z.A., Hashim, S.F.S. and Sakai, E. (2010). Analysis of Mineralogical Component of Palm Oil Fuel Ash with or without Unburned Carbon. *Advanced Materials Research.* 173, 7–11.
- [12] Chandara, C., Sakai, E., Azizli, K. A. M., Ahmad, Z. A. and Hashim, S. F. S. (2010). The effect of unburned carbon in palm oil fuel ash on fluidity of cement pastes containing superplasticizer. *Construction and Building Materials*, 24(9), 1590-1593.
- [13] Chandrasekhar S, Pramada PN, Majeed J.(2006). Effect of Calcination Temperature and Heating Rate on the Optical Properties and Reactivity of Rice Husk Ash. *J Mater Sci* 2006. doi:10.1007/s10853-006-0859-0
- [14] Chandrasekhar S, Satyanarayana KG, Pramada PN, Raghavan P, Gupta TH.(2003). Review Processing, Properties and Applications of Reactive Silica from Rice Husk—an overview. *J Mater Sci* 2003;38:3159–68.
- [15] Chindaprasirt P, Rukzon S, Sirivivatnanon V. (2008). Resistance to Chloride Penetration of Blended Portland cement Mortar Containing Palm Oil Fuel Ash, Rice Husk Ash and Fly Ash. *Construction and Building Materials* 2008; 22:932-938.
- [16] Chindaprasirt, P., S. Homwuttiwong, C. Jaturapitakkul, (2007). Strength and water permeability of concrete containing palm oil fuel ash and rice husk-bark ash. *Construction and Building Materials*, 21: 1492-1499.
- [17] Chusilp, N., Jaturapitakkul, C., Kiattikomol, K., (2009). Utilization of Bagasse Ash as a Pozzolanic Material in Concrete. *Constr. Build. Mater.* 23, 3352-3358.
- [18] *Concrete Composites*, 19(4), 367-372.
- [19] Cordeiro, G.C., Toledo Filho, R.D., Tavares, L.M. and Fairbairn, E.M.R. (2009). Ultrafine grinding of sugar cane bagasse ash for application as pozzolanic admixture in concrete, *Cem. Concr. Res.* 39 (2009) 110–115
- [20] Cordeiro, G.C., Toledo Filho, R.D. and Fairbairn, E.M.R. (2009).Effect of calcination temperature on the pozzolanic activity of sugar cane bagasse ash, *Constr. Build. Mater.* 23 (2009) 3301–3303
- [21] Cordeiro, G.C., Toledo Filho, R.D. and Fairbairn, E.M.R. (2008).Effect Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars, *Cem. Concr. Compos.* 30 (2008) 410–418.
- [22] Frias M, Villar-Cociña E, Valencia-Morales E.(2007). Characterisation of Sugar Cane Straw Waste as Pozzolanic Material for Construction: Calcining Temperature and Kinetic Parameters. *Waste Manage* 2007;27:533–8.
- [23] Ganesan, K., Rajagopal, K. and Thangavel, K.(2007). Evaluation of bagasse ash as supplementary cementitious material, *Cem. Concr. Compos.* 29 (2007) 515–524.
- [24] Gastaldini, A., G.I., N.G., J.S., 2007. Chloride penetration and carbonation in concrete with rice husk ash and chemical activators. *Cement and Concrete composite*, 21: 356-361.
- [25] Hadipramana, J., Riza, F. V., Rahman, I.A., Loon, L.Y., Adnan, S.H. and Zaidi, A.M.A. (2016). Pozzolanic Characterization of Waste Rice Husk Ash (RHA) from Muar, Malaysia. *IOP Conference Series: Materials Science and Engineering.* 160(1).
- [26] Jamil, M., Khan, M.N.N., Karim, M.R., Kaish, A.B.M.A. and Zain, M.F.M. (2016). Physical and chemical contributions of Rice Husk Ash on the properties of mortar. *Construction and Building Materials.* 128, 185–198.
- [27] Jamo, U. and Abdu, S.G. (2015). Characterization of a Treated Palm Oil Fuel Ash. *Science World Journal.* 10(1), 27–31.

- [28] Kizhakkumodam, H., Rao, P., Kizhakkumodam Venkatanarayanan, H. and Rangaraju, P.R. (2015). Effect of grinding of low-carbon rice husk ash on the microstructure and performance properties of blended cement concrete. *Cement and Concrete Composites*. 55, 348–363.
- [29] Madruga F. Western opaline rocks of Spain. Applications with construction materials and evaluation of their pozzolanicity by conductometric techniques. In: Junta de Castilla y León, Consejería de Fomento. Valladolid; 1991. p. 94
- [30] Majumdar AJ, Larner LJ. The Measurement of Pozzolanic Activity. *Cem Concr Res* 1977;7:209–10.
- [31] Malvar, L.J., L.R. Lenke, 2006. Efficiency of Fly Ash in Mitigating Alkali-Silica Reaction
- [32] Montakarnthiwong, K., Chusilp, N., Tangchirapat, W., Jaturapitakkul, C., 2013. Strength and Heat Evolution of Concrete Containing Bagasse Ash from Thermal Power Plants in Sugar Industry. *Mater. Des.* 49, 414–420.
- [33] Morales, E. V., Villar-Cociña, E., Frías, M., Santos, S.F. and Savastano, H. (2009). Effects of Calcining Conditions on the Microstructure of Sugar Cane Waste Ashes (SCWA): Influence in the Pozzolanic Activation. *Cement and Concrete Composites*. 31(1), 22–28
- [34] Neville, A.M., 2002. Properties of Concrete. London: Pearson Education Limited
- [35] Ouyang D. The more valuable utilization of rice husk: making top mineral admixture of concrete. *Cereal Feed Ind* 2003;6:41–2 [in Chinese]
- [36] Ramadhansyah, P.J., Mahyun, A.W., Salwa, M.Z.M., Abu Bakar, B.H., Megat Johari, M.A. and Wan Ibrahim, M.H. (2012). Thermal Analysis and Pozzolanic Index of Rice Husk Ash at Different Grinding Time. *Procedia Engineering*. 50(Icasce), 101–109
- [37] Ramezaniapour, A.A., Kahni, M.M. and Ahmadibeni, Gh.(2009). The Effect of Rice Husk Ash on Mechanical Properties and Durability of Sustainable Concretes. *International Journal of Civil Engineering*. Vol.7, No.2, June 2009.
- [38] Ribeiro, D.V. and Morelli, M.R. (2014). Effect of Calcination Temperature on the Pozzolanic Activity of Brazilian Sugar Cane Bagasse Ash (SCBA). *Materials Research*. 17(4), 974–98
- [39] Rukzon, S., Chindaprasirt, P., 2012. Utilization of Bagasse Ash in High-Strength Concrete: Technical Report. *Mater. Des.* 34, 45–50
- [40] Sata, V., Jaturapitakkul, C. and Rattanashotinunt, C. (2010). Compressive strength and heat evolution of concretes containing palm oil fuel ash.
- [41] Sata V, Jaturapitakkul C, Kiattikomol K. (2007). Influence of Pozzolan from various byproduct Materials on Mechanical Properties of High-Strength Concrete. *Constr Build Mater* 2007;21:1589–98.
- [42] Sata, V., Jaturapitakkul, C. and Kiattikomol, K. (2004). Utilization of palm oil fuel ash in high-strength concrete. *Journal of Materials in Civil Engineering*, 16(6), 623–628
- [43] Soares, M.M.NS., Poggiali, F.S.J, Bezerra, A.C.S., Figueiredo, R.B., Aguilar, M.T.P. and Cetlin, P.R.(2014). The effect of calcination conditions on the physical and chemical characteristics of sugar cane bagasse ash. *Rem: Rev. Esc. Minas [online]*. 2014, vol.67, n.1, pp.33–39. ISSN 0370-4467.
- [44] Tangchirapat, W. and Jaturapitakkul, C. (2010). Strength, drying shrinkage, and water permeability of concrete incorporating ground palm oil fuel ash. *Cement and Concrete Composites*, 32(10), 767–774.