IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Mechanical and Durability Properties of High Strength High Performance Concrete Incorporating Rice Husk Ash

To cite this article: Syamsul Bahri *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **536** 012028

IOP Conf. Series: Materials Science and Engineering **536** (2019) 012028 doi:10.1088/1757-899X/536/1/012028

Mechanical and Durability Properties of High Strength High Performance Concrete Incorporating Rice Husk Ash

Syamsul Bahri[a*], H.B Mahmud[b], Payam Shafigh[c], Edi Majuar[a]

[a]Department of Civil Engineering, Politeknik Negeri Lhokseumawe, Lhokseumawe, Indonesia

[b] Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

[c]Dept of Building Surveying, Faculty Of Built Environment, University of Malaya, 50603Kuala Lumpur, Malaysia

Email: Syamsul_bahri@pnl.ac.id

Abstract. Nowadays, more infrastructure projects require concrete to have a high durability in addition to high strength. High strength high performance concrete (HSHPC) was developed to solve those problems. The weaknesses of HSHPC are high cost of constituent material such as silica fume which is mostly used as supplementary cementitious material (SCM), high cement content at low w/b, low workability and the need of specific curing regime. This research utilized rice husk ash (RHA) as the local waste material as an alternative to silica fume (SF). Five mixes of OPC concrete, 10%, 15% and 20% partial cement replacement by RHA, and 10% partial cement replacement by SF were chosen. The water/cementitious ratio adopted was 0.25 and the total cementitious materials content was 550 kg/m3. The mixing method adopted was the two-step mixing method. In addition to the development of compressive strength, workability, modulus of elasticity and the residue of compressive strength of concrete experienced immerse in 5% solution of magnesium sulphate were also reported. The specimens were cured and tested at 1, 3, 7, 28 and 56 days. Results show that concrete incorporating rice husk ash as 10% partial cement replacement and crushed granite as coarse aggregate with maximum size of 19 mm can achieve compressive strength as high as 110 MPa at 28 days under water curing regime. The HSHPC incorporating 10% RHA showed better overall performance than the HSHPC containing 10% silica fume and the control OPC.

1. Introduction

High strength concrete (HSC) is defined as a mix having cement content higher than 400 kg/m3 and its compressive strength at 28 days of greater than 50 MPa[1]. Furthermore, Jeenu at al. [2] mentioned high strength high performance concrete (HSHPC) as concrete being utilized the full potential of the raw materials to produce an ecological concrete that not only has a high compressive strength but also has a good workability and durability. Such concrete needs additional material to improve the microstructure of regular concrete which leave the pores when hydration of cement and water occurred. Pozzolanic material such as silica fume, slag, fly ash and rice husk ash can make concrete denser as these materials react with CaOH of hydrated cement to produce another CSH and create concrete denser. Silica fume is more favorable than others, but it is expensive compared to cement. Fly ash is the cheapest one but it reacted slowly, and its concrete has less strength than others. Rice husk ash (RHA) is a pozzolanic material because of containing reactive amorphous silica when proper combustion process conducted. There are a lot of raw material in paddy growing countries, - rice husk. In 2013, 745 million metric tons of paddy rice were produced annually worldwide [3] and 20% of that constituted rice husk. By properly burning rice husk and grinding the ash, it can be used as a mineral admixture in concrete production [4]. A high quality of RHA can be produced by burning rice husk under controlled temperatures of less than 700 °C [4][5]. This type of RHA has high amorphous silica, low loss on ignition (LOI) and high SiO_2 content.

Mahmud et al. [6]showed that optimum strength of concrete achieved when 15% RHA used as addition to concrete When it was used as cement replacement, 5% RHA of total binder could improve mechanical properties. Cordiero et al. [7] utilized ultrafine RHA particle size of 3 μm and reported that 20% replacement of cement with RHA produced higher mechanical and durability properties compared to that of control concrete. Even with low amorphous silica content, Rego et al. [8] reported that residual RHA proved to be suitable mineral addition for cements. Chatveera and Lertwattanaruk [9] used RHA with particle size of less than 12 μm and cement replacement up to 20%. It was improved the compressive strength and durability properties of concrete. Chopra et al [10] also reported in self-compacted concrete that the utilization of RHA up to 20% as partial replacement to cement improved the strength and durability properties. Even black RHA with particle size of 12 μm could be used to produce HSC of grade 80, especially at 5% replacement (Mahmud,[11]).

Sulfate attacks concrete in a progressive way and changes its internal microstructure (Marchand, et al., [12]). This process has direct consequences on the engineering properties of the material such as swelling, spalling and cracking. Bolla, et al. [13] used RHA in concrete as a supplementary cementitious material and tested RHA as an alternative to OPC concrete. The cement has been replaced by rice husk ash in the range of 0%, 5%, 10%, 15%, and 20% by weight of cement and then concrete immersed in MgSO4 solution. The result indicates that the RHA improves concrete durability. Bahri, et al. [14] utilized black and grey RHA for replacing 20% of cement weight with RHA and found the RHA concrete improved in mechanical and permeability properties of the concrete.

The aim of this study is to investigate the effectiveness of using RHA on the engineering properties of HSHPC. As mention earlier, most researchers used the average particle sizes of ashes were less than that of cement. This study used the average particles of ashes were coarser than that of previous studies, 3 μm [8] and 10 μm [10]. The average particle sizes of RHA were about 13 μm. Ordinary Portland cement Type I was partially replaced with 10, 15 and 20% of RHA and 10% of SF. This paper presents workability, compressive strength, modulus of elasticity, and the residue of compressive strength when concrete experienced wet and dry cycling. The results of the study would be good information to the concrete industry for applications of RHA in HSHPC.

2. Materials and Method

Ordinary Portland cement (OPC) used was type I conforming to ASTM (CEM 42.5) and its average particle size was 20 μm. The rice husk was received from the rice mills in Kuala Selangor, Malaysia. Meanwhile, RHA (Fig. 1 (a)) was produced from combustion in a Ferro cement furnace in the laboratory with peak temperature below 700^0C.When rice husk are heated from 100 to 600°C, the organic matter like cellulose, lignin etc. decomposes into carbon[15]. RHA were ground using Los Angeles (LA) machine using 40 steel bars of 10.5 kg as abrasive weight and rotating drum for 30,000 cycles lasting 16 h. The average particle size of the RHA was 13 μm after grinding (Fig. 1 (b)).

The chemical characteristic of OPC and RHA were performed by XRF and LOI analysis. Chemical compositions of cement and the RHA are presented in Table 1. It can be seen in this table that SiO_2 content of RHA 85.76% and LOI percentages of RHA 4.05%. Based on ASTM C 618, RHA can be classified as pozzolanic material due to its LOI content lower than 12% and silica content greater than 65%.

(a) (b)

Figure 1. (a) RHA before grinding (b) RHA after grinding

Table 1. Chemical properties of OPC and RHA

Chemical composition (%)	OPC	RHA
Magnesium oxide (MgO)	2.06	0.81
Aluminum oxide (Al_2O_3)	5.60	0.25
Silicon dioxide (SiO_2)	21.28	85.76
Sulfate (SO_3)	2.14	0.31
Calcium oxide (CaO)	64.64	0.74
Iron oxide (Fe_2O_3)	3.38	1.15
Loss on Ignition (LOI)	0.60	4.05

The amorphousness of silica in RHA was checked through XRD analysis. The XRD of RHA in Fig.2 shows that the diffracto-gram of those ashes in broad hump centered around a 2θ angle of 22°, indicating that both ashes is amorphous. The crystalline silica on RHA was possible due to the impurities of the ashes. It was collected from an open discharge in the rice mill yard, which may be subjected to some minor contamination from soil ground. However, Chopra et al.[15]also reported that the silica was predominantly in amorphous form but if incineration temperatures up to 700 °C, some cristobalite existed in RHA.

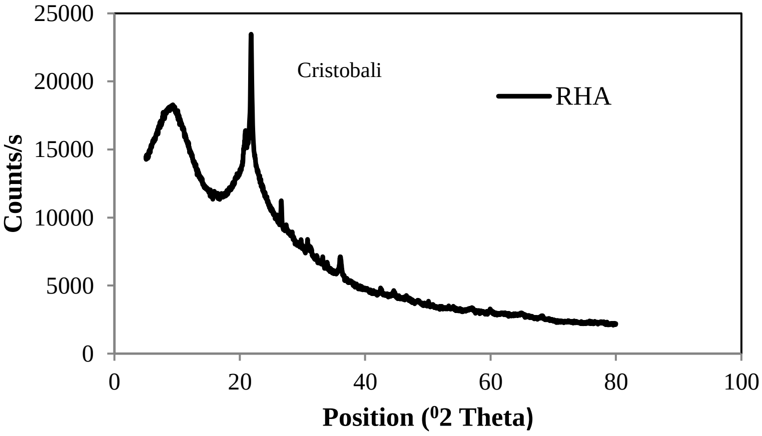

Figure 2. The XRD of RHA

Fine and coarse aggregates used were mining sand and crushed granite with a maximum grain size of 4.75 mm and 19 mm, respectively. The specific gravity of the fine and coarse aggregate was 2.84 and 2.66, respectively.

Water was from water pipe in UM concrete laboratory which free from contamination and was used in all the mixes. The type of superplasticizer used was polycarboxylate either polymer with 40% solid content by mass and was supplied by BASF Sdn. Bhd.

2.1. Mix proportions of concrete mixes

Table 2 shows the mix proportions of concrete mixes incorporating RHA and SF. The control concrete was designed to achieve compressive strength of 100MPa at 28 days based on trial error and absolute volume method. Two step mixing method for mixing concrete was adopted as first step preparing mortar then second step was introduced coarse aggregate. Slump values for all the mixes were designed in the range of 180-200 mm slump. The mixtures contained constant water/binder (w/b) ratio of 0.25 and total binder content of 550 kg/m^3. The percentages of cement replacement by RHA were0%, 10%, 15% and20% and SF was10%.

Table 2. Mix proportions of HSHPC (kg/m^3)

Mix ID	**OPC**	**RHA**	**SF**	**Coarse Agg.**	**Fine Agg.**	**Water**	**SP (l/m^3)**
Control	550	0.0	0.0	1050	702	137.5	2,38
RHA-10	495	55	0	1050	690	137.5	3,49
RHA-15	468	82,5	0	1050	685	137.5	3.93
RHA-20	440	110	0	1050	681	137.5	4.15
SF-10	495	0	55	1050	695	137.5	3,13

2.2. Experimental procedures

The workability of the fresh concretes was measured using a slump test based on BS 1881–102. The slump test was conducted directly before fresh concrete was placed into the molds. To prevent water evaporation from specimens after placement, the specimens were covered with polyethylene sheet. After 24 hours, the concrete molds were dismantled, and the specimens were placed in a water curing tank. For compressive strength test, concrete cubes of 100 x 100 x 100 mm were casted based on BS 1881–116. For splitting tensile strength and modulus of elasticity, concrete cylinders of 100 mm x 200 mm and 150 x 300 mm dimension were used based on BS 1881–117 and BS 1881–12, respectively.

The durability test for concrete was conducted through acceleration test with using 5% solution of magnesium sulphate ($MgSO_4$). The specimen of cube 100x100x100 mm was immersed with the solution for 7 days and then dried for 7 days called as cycle 1. It was conducted for 3 cycles and each end of cycles 3 specimens was tested its compressive strength.

3. Results and Discussion

3.1. Effect of RHA and Silica fume on workability of fresh concrete

Figure 3 shows the comparing dosage of superplasticizer (SP) used in each mix proportions to OPC concrete. The workability of a concrete mix is provided by the paste, which fills the voids between aggregates. The paste acts as a lubricant that reduces internal friction between aggregates while increasing workability [16]. However, RHA concrete needed a certain amount of SP dosage to achieve similar workability to that of fresh OPC concrete. As can be seen in Fig. 3, fresh RHA concrete need more dosage of SP to achieve similar workability. RHA has higher surface areas and high pores inside particles of RHA therefore it needs more water to wet the surface. The available mixing water was reduced, and it affected the workability of fresh RHA concrete. Thus, mixtures containing RHA and SF required additional dosage of SP to achieve the targeted slump value compared to that of OPC concrete. The more percentages RHA involved the more SP dosage needed. It was shown that dosage SP of RHA-10 need only 1.65 times than that of OPC concrete but dosage of SP of RHA-20 needed more 2.19 times than that of OPC concrete. However, the dosage of SF-10 need less dosage SP compared to that of RHA-10, only 1.25 times. It could be due to the silica fume has less pores inside so that it did not absorb water like RHA. To achieve good workability is very important goal in RHA concrete and it ensured appropriate dispersion of the fine particles and proper migration of them into the interface transition zone (ITZ) of concrete [17].

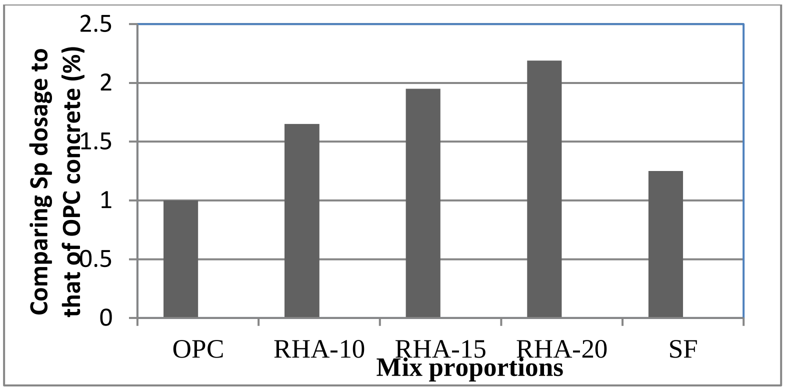

Figure 3. The comparing SP dosages of RHA and SF concretes to that of OPC concrete

3.2. Effect of RHA and SF on compressive strength of concretes

Figure 4 shows developments of the compressive strength of RHA, SF and OPC concretes. The 1 day strength of the RHA-10, RHA-15, RHA-20, SF-10 and OPC concretes was 54, 48,7, 35,7, 51,2 and 73,5 MPa, respectively. It is an interesting phenomenon that concrete containing RHA and SF exhibited lower compressive strength at early age compared to that of OPC. Those concretes have less cement content as they were replacement by RHA and SF. The RHA and SF will react with CaOH of hydrated cement to form another CSH. However, mostly those ashes reacted after 3 days onward depended how much the ashes used. The delayed setting time of the paste significantly affected the mechanical properties at early ages [18]. As mention earlier, the RHA and SF concrete needed more superplastic than the OPC concrete so that the excessive dosage of SP in RHA and SF affected its early compressive strength.

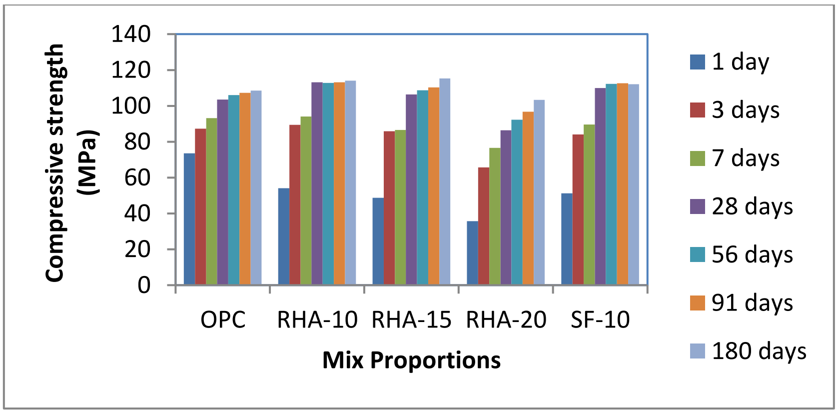

Figure 4. Development of compressive strength of concretes

It can be seen from figure 8 that RHA-15 showed the compressive strength developed after 56 days. However, RHA-20 showed less developed than other RHA concrete. It means that replacement 15% cement with RHA is the optimum partial replacement. Other researcher showed that the 20%

replacement cement with RHA was the optimum. It could be true for the concrete below 60 MPa as it can be produced with higher ratio of w/c.

From fig.4, the improvement in strength occurred in the RHA and SF concrete at later ages. Tangapasit et al. [19] reported that the finer particle size of pozzolan material could improve the packing effect of the material. Scrivener et al. [20] pointed out that the particle size of supplementary cementitious material should be less than the particle size of cement in order to improve ITZ of concrete. The 28-day compressive strength of the RHA-10, RHA-15, RHA-20 and SF-10 concrete were 113.2, 106.4, 86,4 and 110MPa, respectively. The significant improvement in the RHA and SF concrete could be related to the pozzolanic reaction of RHA and SF with $Ca(OH)_2$ which was released from hydration of cement. Therefore, more calcium silicate hydrate (CSH) was produced. This process filled in the pore system, making RHA and SF concrete more homogeneous and denser than the control concrete [21].

3.3. Effect of RHA and SF on modulus of elasticity of concretes

The static modulus of elasticity of the hardened cement paste and the aggregate in HSHPC is different than that of normal concrete. The behavior of HSHPC was more monolithic and the strength of the aggregate matrix interface was higher. Therefore, there is less bond micro cracking in HSHPC. The linear part of stress-strain curve could achieve as high as 85% of the failure stress in HSHPC concrete [22].

Table 3. Static modulus of elasticity

Mix ID	Static modulus of elasticity E (GPa)		
	7 d	28 d	91 d
OPC	36.0	39.6	45.8
RHA-10	40.3	43.8	47.6
RHA-15	39.4	42.9	46.2
RHA-20	35.2	37.3	44.3
SF-10	41.2	42.3	47.2

Table 3 shows the static modulus elasticity of concrete with w/b of 0.25, replacement percentages of RHA and ages of curing Generally, the results in Table 3 show that the static modulus of OPC concrete is less than RHA and SF concrete regarding replacement and ages; only RHA-20 replacement is lower than OPC concrete. Less compressive strength of RHA-20 concrete and more axial strain was the reason of its less static modulus of elasticity. The RHA-10, and RHA-15and SF-10 concrete show their static modulus of elasticity was higher than that of OPC concrete at any days of testing. The results of static modulus are shown in Table 3. The values of the static modulus of elasticity were in the range of 36.0 – 47.6GPa. It can be noted that the addition of RHA to concrete exhibited marginal increase on the elastic properties, the highest value was recorded for RHA10 mixture due to the increased reactivity of the RHA. Concretes incorporating pozzolanic materials usually show comparable values for the elastic modulus compared to the OPC concrete ([24] [25] [26].

3.4. Effect of RHA and SF concrete immersed in solution of magnesium sulfate in wet dry cycles

Concrete in certain environment condition can experience degradation of strength. Degradation of concrete can be caused by various causes: fire, aggregate expansion and sea water degradation, etc. In this section, the sulphate attack on HSHPC containing RHA and SF will be elaborated. Sulphate is available in soil and sea water. In this study, the sea water condition was stimulated by making dry and wet condition as tidal zone in sea water. Concrete that has contacted with sulphate can experience the chemical changes in cement. The deterioration mechanism is the chemical change in cement caused microstructural effect which the cement binder is weakening. It is worthy to note that sulphate solution caused damage through crystalline and re-crystalline in porous concrete.

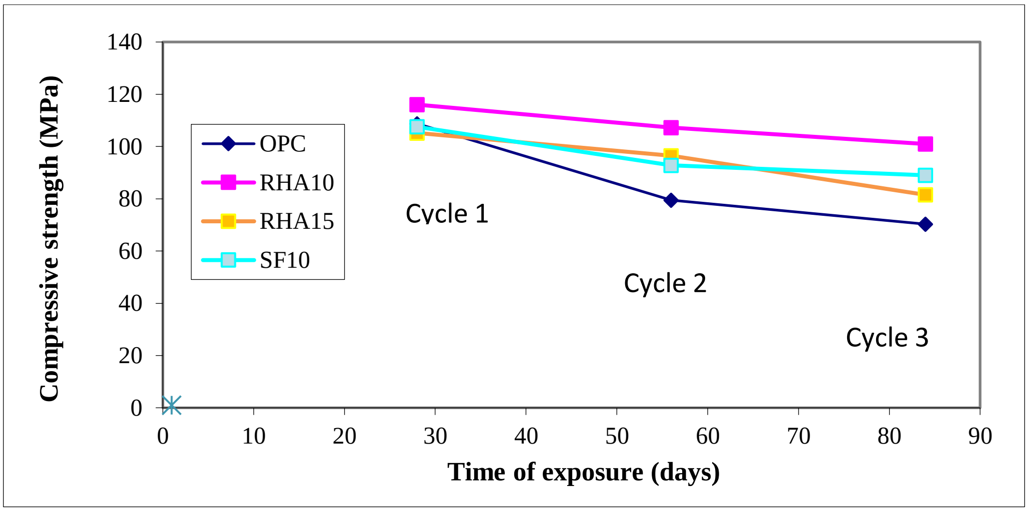

Figure 5. Development of compressive strength of concrete on magnesium sulphate environment

Figure 5 shows the degradation of concrete after the concrete was exposed to magnesium sulphate in three cycles. RHA, SF and control concrete affected by magnesium sulphate after cycle 1. In cycle 1, the concrete experienced the improving compressive strength. It could be the process of crystalline was barely enough close to pores of concrete which caused concrete denser. However, in further cycling the concrete experience degradation as compressive strength of concrete decreased. It could be the magnesium sulphate solution in concrete pores started to crystalline and re-crystalline due to wetting and drying cycling. It caused the concrete to expand and cause micro crack its surrounding. The control concrete experienced worst condition compared than the RHA and SF concrete. The RHA-10 concrete experienced less degradation than OPC, RHA-15 and SF-20 concrete. In addition, the RHA-15 and SF-10 concrete experienced almost similar degradation.

4. Conclusion

Based on the investigation on fresh, strength and durability properties of concrete containing RHA and SF the following can be concluded that utilizing RHA and SF in HSPC concrete increased the dosage of SP used compared to that of control concrete. RHA can be used as partial replacement in HSHPC concrete up to 15% and increased 15% compressive strength compared to control concrete. Additionally, the static modulus of RHA and SF concrete are higher than that of OPC concrete regarding replacement and ages; only RHA-20 replacement is lower than OPC concrete. The effect of RHA, SF and OPC concrete immersed in 5% magnesium sulphate solution was the control concrete experienced worst condition compared than that of the RHA and SF concrete. The RHA-10 concrete experienced less degradation than OPC, RHA-15 and SF-20 concrete.

5. Acknowledgement

The authors would like to thank the Ministry of Science and Environment of Malaysia for awarding the UMRG Grant no: UMRG RP018/012C to carry out research on high strength rice husk ash concrete. Authors also were supported by Head department of civil engineering, Politeknik Negeri Lhokseumawe.

References

[1] L.T. Phan. High-strength concrete at high temperature-An overview. in Utilization of High Strength/High Performance Concrete, 6th International Symposium Proceedings. 2002.

[2] Jeenu, G., Vinod, P., & Mangal, L. (2012). Packing characteristics of aggregates for high performance concrete. Int. J. Earth Sci. Eng, 5(5), 1424-1431.

[3] FAO, Rice market monitor, vol XVIII. 2015, Issue 1.

[4] P. Chindaprasirt, S. Homwuttiwong, and C. Jaturapitakkul, Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash. Construction and Building Materials, 2007. 21(7): p. 1492-1499.

[5] G.R. de Sensale, Strength development of concrete with rice-husk ash. Cement and Concrete Composites, 2006. 28(2): p. 158-160.

[6] H.B. Mahmud, E. Majuar, M.F.M. Zain, A.R.A. Rauf, and K.B. Beh, Feasibility of Using Black Rice Husk To Produce High Strength Concrete in Proc., Int. Conf. . 2003, The Concrete Institute of Australia (CIA): Brisbane, Australia. p. 1239-1249.

[7] G.C. Cordeiro, R.D. Toledo Filho, and E.d.M.R. Fairbairn, Use of ultrafine rice husk ash with high-carbon content as pozzolan in high performance concrete. Materials and Structures, 2009. **42**(7): p. 983-992.

[8] J. Rêgo, A. Nepomuceno, E. Figueiredo, and N. Hasparyk, Microstructure of cement pastes with residual rice husk ash of low amorphous silica content. Construction and Building Materials, 2015. **80**: p. 56-68.

[9] B. Chatveera and P. Lertwattanaruk, Durability of conventional concretes containing black rice husk ash. Journal of environmental management, 2011. **92**(1): p. 59-66.

[10] D. Chopra and R. Siddique, Strength, permeability and microstructure of self-compacting concrete containing rice husk ash. Biosystems Engineering, 2015. **130**: p. 72-80.

[11] H. Mahmud. Properties of High Strength Concrete Incorporating Black Rice Husk Ash. in The 2nd ASEAN Civil Engineering Conference 2010. Vientiane, Laos.

[12] Marchand, J., Odler, I., & Skalny, J. P. (2003). Sulfate attack on concrete. CRC Press

[13] Bolla, R. K., Ratnam, M. K. M. V., Raju, U. R., Bolla, R. K., Ratnam, M. K. M. V., & Raju, U. R. Experimental Studies on Concrete with Rice Husk Ash as a Partial Replacement of Cement Using Magnesium Sulphate Solution. International Journal, 1, 333-340.

[14] Bahri, S., Mahmud, H. B., & Shafigh, P. (2018). Effect of utilizing unground and ground normal and black rice husk ash on the mechanical and durability properties of high-strength concrete. Sādhanā, 43(2), 22

[15] S. Chopra, S. Ahluwalia, and S. Laxmi. Techology and manufacture of rice husk masonry cement. in ESCAP/RCTT third workshop on rice husk ash cements, New Delhi. 1981.

[16] S. Mindess, F. Young, and D. Darwin, Concrete (2nd ed.). 2003, New Jersey, USA: Prentice-Hall.

[17] J. Hu and P. Stroeven, Properties of the interfacial transition zone in model concrete. Interface Science, 2004. **12**(4): p. 389-397.

[18] M. Heikal and I. Aiad, Influence of delaying addition time of superplasticizers on chemical process and properties of cement pastes. Ceramics Silikaty, 2008. **52**(1): p. 8.

[19] J. Tangpagasit, R. Cheerarot, C. Jaturapitakkul, and K. Kiattikomol, Packing effect and pozzolanic reaction of fly ash in mortar. Cement and Concrete Research, 2005. **35**(6): p. 1145-1151.

[20] K.L. Scrivener, A.K. Crumbie, and P. Laugesen, The interfacial transition zone (ITZ) between cement paste and aggregate in concrete. Interface Science, 2004. **12**(4): p. 411-421.

[21] S. Chowdhury, A. Maniar, and O. Suganya, Strength development in concrete with wood ash blended cement and use of soft computing models to predict strength parameters. Journal of advanced research, 2015. **6**(6): p. 907-913.

[22] [22].Dancygier, E. R., , A. N., &Paultre, P. (2010). Stress–strain curve for concrete in circular columns based on elastoplastic analysis. Materials and structures, 43(1-2), 63.

[23] [23]. P. Chindaprasirt, P. Kanchanda, A. Sathonsaowaphak, and H. Cao, Sulfate resistance of blended cements containing fly ash and rice husk ash. Construction and Building Materials, 2007. **21**(6): p. 1356-1361.
[24] [24]. C.L. Hwang and S. Chandra, The use of rice husk ash in concrete. 1997, William Andrew Publishing/Noyes, Norwich, NY. p. 184-234.
[25] [25]. P. Mehta. The chemistry and technology of cements made from rice husk ash. in Proc. UNIDO/ESCAP/RCTT Workshop on Rice-Husk Ash Cement, Peshawar, Pakistan. 1979.
[26] [26]. A.C. 318, Building code requirements for reinforced concrete. 1995: American Concrete Institute.