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Research Article

Maximizing Sustainability of Concrete through the Control of Moisture Rise and Drying Shrinkage Using Calcined Clay Pozzolan

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The Ghanaian concrete industry is really a booming industry due to many infrastructural developments and the surge in residential development. However, many developmental projects that utilize concrete do suffer from the negative impact of moisture rise including paint peeling-off, bacterial and fungi growth, and microcracks as well as unpleasant looks on buildings. Such negative outlook resulting from the effects of moisture rise affects the longevity of concrete and hence makes concrete less sustainable. This study seeks to develop materials that could minimize the rise of moisture or ions through concrete medium. The experimental works performed in this study included pozzolanic strength activity index, water sorptivity, and shrinkage test. Calcined clay produced from clay was used as pozzolan to replace Portland cement at 20%. The strength activity test showed that the cement containing the calcined material attained higher strength activity indices than the control. The thermal gravimetric analysis showed that the pozzolan behaved partly as a filler material and partly as a pozzolanic material. The sorptivity results also showed that the blended mix resulted in lower sorptivity values than the control mortar. The study recommends that calcined clay and Portland cement mixtures could be used to produce durable concrete to maximize sustainability.

1. Introduction

Rapid urbanization and population growth in this century have resulted in the high consumption of concrete which is used for road pavement constructions as well as residential and office buildings. Concrete is known to be the second highest consumed product after water [1]. Sustainable concrete in other words refer to durable concrete. Durable concrete has been described as concrete that has the ability to resist environmental risks and maintaining desired engineering properties [2]. As long as there is rapid urbanization in many developing countries and an increase in population growth, sustainable concrete would be a priority for many of such nations. The creation of durable concrete for infrastructure and building projects would minimize the long term negative impact on building structures whilst preserving these structures for generations. These negative impacts include destruction of cement matrix which occurs from the attack of harmful and aggressive ions such as chlorides, acids, and sulphates. These chemical ions penetrate through the capillary pores of the cement matrix [3]. Therefore, the resistance of concrete to the ingress of ions is fundamental to concrete sustainability.

Ghana has a growing economy and therefore there is a surge in the building and infrastructure development. The construction industry in the country depends hugely on concrete for almost every infrastructure and building development especially in the major cities. However, in recent times, many engineers and developers have been struggling with the negative impact of moisture or ions rising through the base of many structures from soils. Moisture rise also known as rising damp through concrete medium is usually not realized during the early periods of structural development. Long periods after completion of projects are rather seen sometimes. The impact of rising damp or moisture rise in building projects especially at the completion stage could be very unpleasant, worrying, and very expensive to fix.

Moisture rise in concrete is caused fundamentally by capillary suction in porous building materials [4]. The service life or durability of concrete structures strongly depends on the material transport properties including permeability, sorptivity, and diffusivity which are controlled by the micropores in the concrete [5]. It has been mentioned by Martys [6] that achieving durable concrete is related to reducing porosity of cement paste. This is because cement paste unlike aggregate creates continuous capillary pores which facilitate the transport mechanism. Capillary absorption properties of porous building materials could be analyzed using the measure of sorptivity [4]. This method is reported to be not only cheaper but also reliable and simple [7].

The extent of moisture rise through concrete medium could be related to the type of materials used for concrete production. Proper and intelligent use of Portland cement and pozzolans are known from literature to be one of the possible ways to control moisture rise through concrete [8, 9]. In this study pozzolan produced from calcined clay was used as a partial replacement of Portland cement. The main aim of the study was to minimize moisture rise in concrete medium through the use of calcined clay pozzolan and Portland cement mixtures. In this regard the main research question for the study was as follows: "could the introduction of Ghanaian calcined clay pozzolan reduce moisture rise through concrete materials?"

2. Material and Methods

2.1. Materials. The materials used for the study included Portland cement, powdered calcined clay, sand, a high range water reducer (HRWR), and potable water. The Portland cement was obtained from Ashgrove in Chanute, Kansas, the United States, which satisfied the ASTM type I/II type cement. Clay used was sourced from the Nyamebekyere area in the Ashanti region of Ghana. The HRWR used was a polycarboxylate liquid, Glenium 7500 obtained from BASF Company in the United States. The sand used was in conformity with the ASTM C778 standards. The potable water was from the running tap of University of Missouri-Kansas City (UMKC). The cement and the clay chemical compositions are illustrated in Table 1.

Table 1: Chemical compositions of Portland cement and clay.

Property	ASTM type I/II	Raw clay
Physical		
Fineness (m^2/kg)	401.7	
Specific gravity	3.13	
Chemical		
SiO_2 (%)	20.49	59.70
Al_2O_3 (%)	4.26	25.53
Fe_2O_3 (%)	3.14	5.22
CaO (%)	63.48	0.16
MgO (%)	2.11	1.37
SO_3 (%)	2.9	0.07
$Na_2O + K_2O$ (%)	0.49	2.41
LOI (%)	2.2	4.50
Mineralogical		
C_3S (%)	56	
C_2S (%)	15	
C_3A (%)	6	
C_4AF (%)	9	

2.2. Methods

2.2.1. Calcination of Clay, Mortar Preparation, and Strength Activity Index Determination. The clay material was calcined in a laboratory furnace (Thermolyne 8000) at a temperature of 800°C. The calcined material was sieved through a 75 μm mesh and the underpass used to replace 20% of Portland cement. The fineness of the calcined material was 420 m^2/kg. The binder formed was used to prepare mortars. Mortar preparation was performed in accordance with ASTM C109. The required flow for the mortars was determined in accordance with ASTM C1475. The flow of mortars containing calcined clays was adjusted with the addition of HRWR. This was done because the addition of calcined clays produces stiff mortars. Table 2 shows the mortar mixture proportions used for the determination of compressive strength. The mortars produced were sealed under plastic sheet and wet burlap for 24 hours and then demolded. The demolded mortar specimens were transferred to a curing tank containing lime-saturated water. The curing periods for the mortar specimens were 7 and 28 days. Strength activity index (SAI) was used to determine the maximum strength. The mortar sample which recorded the maximum SAI was used for the water sorptivity test and the shrinkage test. In all, a total number of 12 mortar specimens were produced, six for the 7 days' strength test and the other six for the 28 days' strength determination. SAI was determined using this formula:

$$\text{SAI} = \frac{A}{B} \times 100\%, \quad (1)$$

where A is mortar strength cured at 7 or 28 days and B is the mortar strength of the control.

2.2.2. Degree of Hydration. The degree of hydration was determined using the thermal gravimetric analyzer. Approximately 35 mg of the hydrated samples was used in a Mettler Toledo TGA/SDTA 851e analyzer heated to 750°C, ramping at 10°C per minute in N_2 gas. The $Ca(OH)_2$ content was deduced from the equation provided by Yu et al. [10] and given as

$$\text{Content of CH} = \left(\frac{T_b}{18} + \frac{2}{3} \times \frac{T_c}{44}\right) \times 74, \quad (2)$$

where T_b is the amount of matter decomposition occurring between 400 and 550°C and T_c similarly is the amount of material decomposition above 550°C.

Table 2: Mortar mix proportion for determining strength activity index.

Temp (°C)	Mix name	Mass (g)				w/b	HRWR (%)	Flow (%)
		Cement	Clay	Sand	Water			
Control	Control	500	0	1375	242	0.485	0.0	106
800	20P800	400	100	1375	242	0.485	0.4	110

2.2.3. Sorptivity Test. The sorptivity test was performed in accordance with ASTM C1585. 25 mm cube mortar samples cured after 1 and 7 days were conditioned. For the conditioning process, samples were placed in a desiccator containing saturated solution of potassium bromide (KBr) placed at the bottom part inside the dessicator without making any contact with the specimen. KBr was used to maintain a high humidity environment (about 98%). The desiccator and content were placed in an oven at a temperature of 50°C for 3 days. After the three days, the dessicator and content were removed from the oven. Mortar samples were placed in sealable transparent plastic containers and placed in an environmental chamber maintained at 50% humidity and 23°C for at least 15 days. The sealed plastic bags were removed from the chamber after the conditioned period and samples taken out from the sealed plastic bags for their weight measurement. The sides and the top part of the specimens were covered with a black duct tape leaving the side opposite to the top part uncovered. This was done to allow water to flow in one direction. The mass of the covered specimen was recorded as the initial mass of water absorption. A support device was placed at the bottom of a rubber container (shoe box) and filled with tap water up to the height of the support device. The uncovered portion of the mortar specimen was placed on the support device while the water level was increased to about 2 mm above the specimen from the bottom.

The equation used for sorptivity is given below

$$i = S\sqrt{t}, \quad (3)$$

where S is the sorptivity measured in g per mm^2 (of wetted area) per $sec^{1/2}$. It is easily determined from the slope of the linear part of i versus $t^{1/2}$ curve [11].

An average of three mortar specimens was used for the absorption calculations. The gain in mass per unit area over the density of water was plotted against the square root of the elapsing time. The slope of the line of best fit of these points was taken as the sorptivity value.

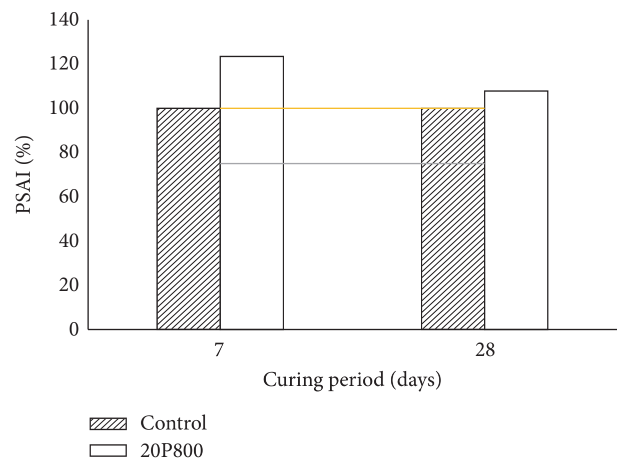


Figure 1: Strength activity indices of Portland cement (control) and blended cement mortars.

3. Results and Discussions

3.1. Strength Activity Index. Figure 1 presents the strength activity indices of Portland cement labelled as control and the clay pozzolans calcined at 600–1000°C. The ASTM C618 specifies that the 7- and 28-day SAI of any suitable pozzolanic material must be greater than 75% of the control mortar. Figure 1 shows that all the mortars that contained the calcined materials satisfied the ASTM C618 specifications. 20P800 gave the maximum SAI at 7 and 28 days. This shows that the material calcined at 800°C was well calcined and contained more reactive pozzolanic phases that reacted well with Portland cement. The SAI results indicated that calcined clay at 800°C that was used to replace 20% of Portland cement (20P800) yielded the optimum mortar mixture proportion.

3.2. Degree of Hydration. Figure 2 shows the degree of hydration of the control and the Portland cement containing calcined clay pozzolan. The degree of hydration of the control at 3 and 7 days was 16% and 19%, respectively, whereas that of 20P800 was 23% and 24%, respectively. The high degree of hydration of 20P800 at 3 and 7 days shows that there was a filler effect due to the incorporation of the pozzolan. The filler effect creates nucleation sites on the surface of the pozzolanic material which facilitates the hydration of cement products that enhances early age strength [12]. This explains the reason behind the high strength activity index of 20P800 compared to the control at seven days.

At 28 days of curing, the $Ca(OH)_2$ generated from the control (Con) paste was 20% whereas that of pozzolan paste (20P800) was 16%. The decrease in the content of $Ca(OH)_2$ at 28 days is an indication of pozzolanic reaction [13]. Pozzolanic reaction reduces content of $Ca(OH)_2$ through the conversion of $Ca(OH)_2$ to calcium aluminosilicate hydrates that enhances strength [14]. Kamali and Ghahremaninezhad [15] reported that pozzolanic reaction occurs slowly at later ages of curing. The higher strength activity index of 20P800 than the control is attributed to pozzolanic reaction.

3.3. Sorptivity Studies. Figure 3 presents the sorptivity studies of the control and the optimum blended mortar mix (20P800). The figure shows a plot of sorptivity (I) measured in millimeters (mm) against time (sec). The initial (Si) and

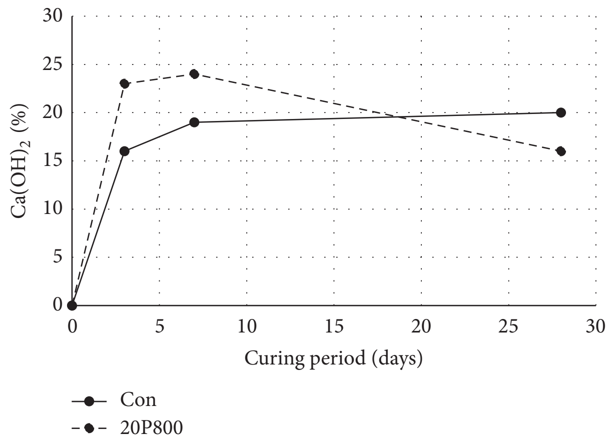


Figure 2: Degree of hydration.

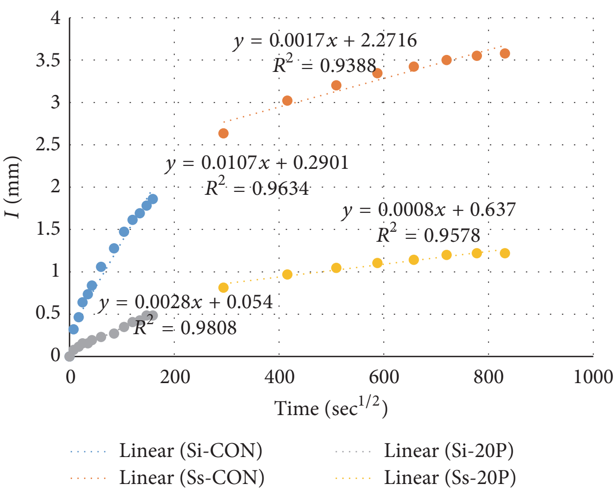


Figure 3: Sorptivity results of control and blended calcined clay/Portland cement mortars.

secondary (Ss) sorptivity coefficients for the control mortar were 0.0107 and 0.0017, respectively, whereas the Si and Ss for the blended mortar mix were 0.0028 and 0.0008, respectively. The results show that the initial (Si) and secondary (Ss) sorptivity values for the control were much higher than those of the blended cement mortar. These indicate that the inclusion of calcined clay as pozzolan resists the ingress of moisture. This result was in conformity with the studies of Olufemi and Folagbe [16] and Kakhuntodd et al. [17] that indicated lower sorptivity of blended cement than unblended cement. The studies of Song et al. [8] and Yildiz [9] also found that pozzolanic materials used as part of the binder component in concrete medium reduced the ingress of harmful ions. The reduction of the pores within the cement matrix could be due to the formation of stable calcium silicate and aluminate compounds which fill pores within the matrix during hydration.

4. Conclusions and Recommendations

4.1. Conclusions. The study analyzed the performance of clay calcined at 800°C with unblended Portland cement matrix using the PSAI, TGA, and sorptivity techniques. From the results, the following conclusions were drawn:

(1) Clay calcined at 800°C and used to replace 20% by weight of Portland cement gave a higher pozzolanic strength activity than plain Portland cement.

(2) The calcined material behaved as partly a filler material at the early period of cement hydration and partly as a pozzolanic material at the late period of cement hydration. The filler effect improved the 7 days' strength whereas the pozzolanic effect improved the 28 days' strength.

(3) The sorptivity studies showed that mortar containing 20% calcined clay pozzolan at 800°C has the ability to refine the pore structures of cement paste. This inhibits the transport of moisture through concrete medium.

4.2. Recommendations. The study recommends the utilization of calcined clay pozzolan for the Ghanaian concrete industry. This could enhance concrete durability and consequently the sustainability of concrete.

Competing Interests

The authors declare that they have no competing interests.

References

[1] C. M. Hansson, "Concrete: the advanced industrial material of the 21st century," *Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science*, vol. 26, no. 6, pp. 1321–1341, 1995.

[2] M. Thomas, R. D. Hooton, C. Rogers, and B. Fournier, "50 years old and still going strong," *Concrete International*, vol. 34, pp. 35–40, 2012.

[3] S. H. Kosmatka and M. L. Wilson, *Design and Control of Concrete Mixtures*, EB001-15, Portland Cement Association, Skokie, Ill, USA, 15th edition, 2011.

[4] A. S. Guimarães, J. M. P. Q. Delgado, and V. P. de Freitas, "Rising damp in walls: evaluation of the level achieved by the damp front," *Journal of Building Physics*, vol. 37, no. 1, pp. 6–27, 2013.

[5] N. M. Sutan, S. Hamdan, H. R. Sobuz et al., "Porosity and strength of pozzolan modified cement systems," *Concrete Research Letters*, vol. 2, no. 4, pp. 326–335, 2011.

[6] N. S. Martys, "Survey of concrete transport properties and their measurement," NISTIR 5592, US Department of Commerce, pp 1–40, 1999.

[7] D. Lockington, J.-Y. Parlange, and P. Dux, "Sorptivity and the estimation of water penetration into unsaturated concrete," *Materials and Structures*, vol. 32, no. 5, pp. 342–347, 1999.

[8] H.-W. Song, S.-W. Pack, S.-H. Nam, J.-C. Jang, and V. Saraswathy, "Estimation of the permeability of silica fume cement concrete," *Construction and Building Materials*, vol. 24, no. 3, pp. 315–321, 2010.

[9] K. Yildiz, "The performance of silica fume admixtured concrete under the effect of ammonium sulfate," *E-Journal of New World Sciences Academy: Technological Applied Sciences*, vol. 3, no. 2, pp. 1–9, 2008 (Turkish).

[10] L. Yu, S. Zhou, and W. Deng, "Pozzolanic activity of volcanic rocks from Southern Jiangxi Province, China," *Journal of Sustainable Cement-Based Materials*, vol. 5, no. 3, pp. 176–198, 2015.

[11] B. B. Sabir, S. Wild, and M. O'Farrell, "A water sorptivity test for mortar and concrete," *Materials and Structures*, vol. 31, no. 212, pp. 568–574, 1998.

[12] B. Lothenbach, K. Scrivener, and R. D. Hooton, "Supplementary cementitious materials," *Cement and Concrete Research*, vol. 41, no. 12, pp. 1244–1256, 2011.

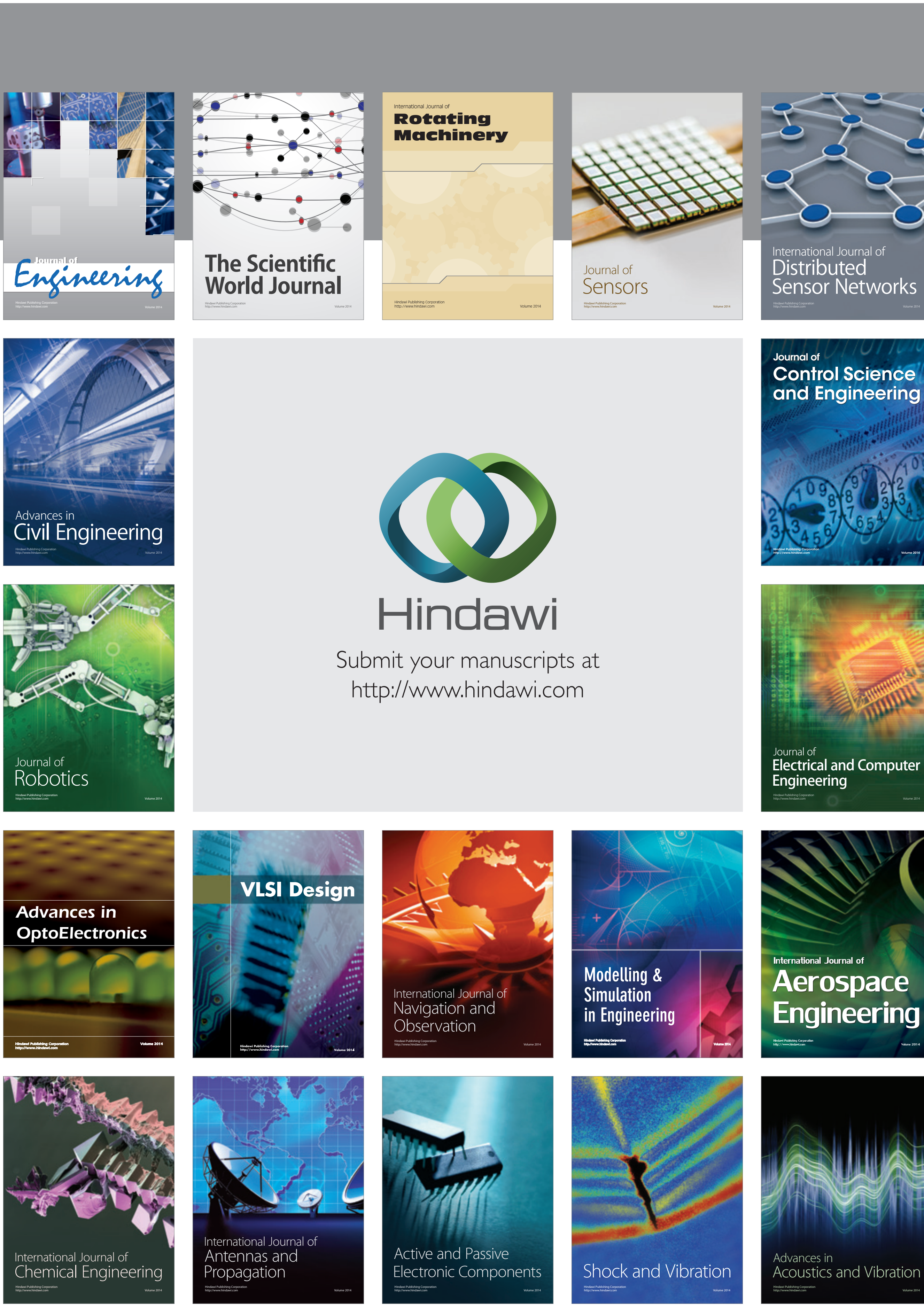
[13] K.-L. Lin, B.-Y. Chen, C.-S. Chiou, and An Cheng, "Waste Brick's potential for use as a pozzolan in blended Portland cement," *Waste Management and Research*, vol. 28, no. 7, pp. 647–652, 2010.

[14] L. Lam, Y. L. Wong, and C. S. Poon, "Degree of hydration and gel/space ratio of high-volume fly ash/cement systems," *Cement and Concrete Research*, vol. 30, no. 5, pp. 747–756, 2000.

[15] M. Kamali and A. Ghahremaninezhad, "An investigation into the hydration and microstructure of cement pastes modified with glass powders," *Construction and Building Materials*, vol. 112, pp. 915–924, 2016.

[16] S. Olufemi and Folagbe, "Sorptivity of cement combination concretes containing Portland cement, fly ash and metakaolin," *International Journal of Engineering Research and Applications* , vol. 2, pp. 1953–1959, 2012.

[17] N. Kakhuntodd, P. Chindaprasirt, C. Jaturapitakkul, and S. Homwuttiwong, "The investigation of water permeability of high volume pozzolan concrete," *Journal of Science Technology*, vol. 31, pp. 563–570, 2012.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