INFLUENCE OF RICE HUSK ASH (RHA) ON THE DRYING SHRINKING OF MORTAR

Benyamin Rasoul[a]*

Keywords: Physical properties; chemical composition; fineness; drying shrinkage, crystalline silica; rice husk ash.

The possibility of using of rice husk ash (RHA) in the mortar has been studied. The impact of physical properties and chemical composition of RHA on dry-shrinkage of mortar is a potential problem, especially in the context of the increased use of new generation solutions and the development of new materials to ensure sustainability. In this study, the effects of RHA content, RHA particles size (fineness) and silica structure have been evaluated. Comparisons are made over the full test period and at specific periods ranging from 3 days to 180 days. Incorporation of RHA provided lower dry shrinkage, where the amount of decrease in dry shrinkage increased with increase crystalline silica content and coarse particles size when compared to the control Ordinary Portland Cement (OPC) mixture, with finer RHA giving better improvement. Fine RHA exhibited the highest shrinkage value due to the effect of microfine particles which increases its shrinkage values considerably.

* Corresponding Authors
Fax:
E-Mail: br86@brighton.ac.uk
[a] University of Brighton
[b] 7 Manton road, Brighton/UK

Introduction

Cracking in the concrete bridge decks is a well-documented problem. The problem is particularly severe for a large structure, such as a large concrete floor. Cracking contributes to the deterioration of the structures and allows the ingress of water to the reinforcement, which may lead to corrosion. Cracking increases the maintenance costs, reduces the service life and may result in disruptive and costly repairs. Experience shows that a combination of shrinkage and thermal stresses causes most structure cracking. Efforts have been made to reduce the cracking by designing concrete mixes for minimal shrinkage and improving methods of construction, placement, and finishing. Various admixtures such as silica fume,[1] and carbon fibres[2] have been used to reduce the drying shrinkage. Moreover, to conserve raw materials involved in the production process, eliminate wastes that impact the environment, and to improve the technical properties of concrete, previous studies have demonstrated the feasibility of replacing cement with agro-industrial sub-products. One such example is the ash obtained from burning rice husks, as rice is one of the most cultivated grains in the world. Research has shown that rice husks can improve concrete's mechanical properties[3] and durability.[4] However, few studies have focused on the influence of the rice husk ash content on dry mortar shrinkage.

Experimental

Materials

Three types of RHA (A, B and C) were used in the experimental research are brought from India, While RHA-D obtained by re-burned RHA-C at relatively high temperatures (550 ºC) for 6 h. Properties of rice husk ash, the typical physical properties and chemical composition are given in Tables 1 and 2.

Table 1. Physical properties of RHA samples.

Physical properties	RHA			
	A	B	C	D
Specific surface area, $m^2\ g^{-1}$	0.537	0.587	0.692	0.808
Mean particle size, μm	23.397	20.948	15.804	12.64

Test procedures

The dry-shrinkage of RHA mortar mixtures were measured according to the recommendations made by ASTM standards ASTM C 490 standard.[5] For each mix under investigation, four specimens with dimensions of 400 mm × 50 mm × 50 mm were studied for each composition. After preparing and mixing, each mixture was carefully filled into two prisms moulds. The moulds kept for 24 h then de-moulded and the first reading, which is the initial reading, was recorded by using the apparatus of measurement of dry-shrinkage. The values of dry shrinkage represent the average of two specimens for each batch. The samples were stored in a room at 23 ± 2 °C at a relative humidity of 50 ± 10 % for air drying. Shrinkage readings were performed at 7, 14, 21, 28, 35, 56, 91, and 180 days. These readings were performed in an expandable comparator with a digital marker accurate to 0.001 mm.

Measurement of length change of specimens

To calculate the length change in OPC and RHA mortars, the ASTM C 490 formula was used (eqn. 1), where L = % change in length at x age, L_x = comparator reading of specimen at x age minus comparator reading of reference bar at x age in mm, L_i = Initial comparator reading of specimen minus comparator reading of reference bar at that same time in mm and G = nominal gage length 250.

$$L = \frac{L_x - L_i}{G}100 \quad (1)$$

Table 2. Chemical composition of RHA samples.

RHA sample	Chemical composition (% wt. of ash)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	P_2O_5	SO_3	MnO
RHA-A	92.10	1.066	0.241	0.719	1.366	0.403	0.076	0.109
RHA-B	89.31	1.389	0.391	0.987	1.813	0.747	1.104	0.166
RHA-C	84.30	1.066	0.175	0.729	1.522	0.675	0.083	0.144
RHA-D	93.49	1.186	0.202	0.971	1.587	0.663	0.084	0.115

Table 3. The mix proportion of RHA mortar dry-shrinkage test.

Batch No.	Cement, kg m^{-3}	RHA, kg m^{-3}	Water, kg m^{-3}	SP*, kg m^{-3}	SP (% wt. of binder)
OPC	587	0	292	1.47	0.25
5	558	29	292	1.47	0.25
10	528	59	292	1.47	0.25
15	499	88	292	1.47	0.25
20	470	117	292	1.47	0.25
30	411	176	290.56	2.94	0.50
40	352	235	287.63	5.87	1.00
50	293.5	293.5	281.76	11.74	2.00
60	235	352	270.02	23.48	4.00

Mix proportion and Curing

The mix proportions of the batches are given in table 3. Where the water binder ratio (w/b) was constant at 0.50 and the fine aggregate (silica sand) used was 1320 kg m^{-3}.

Results and Discussion

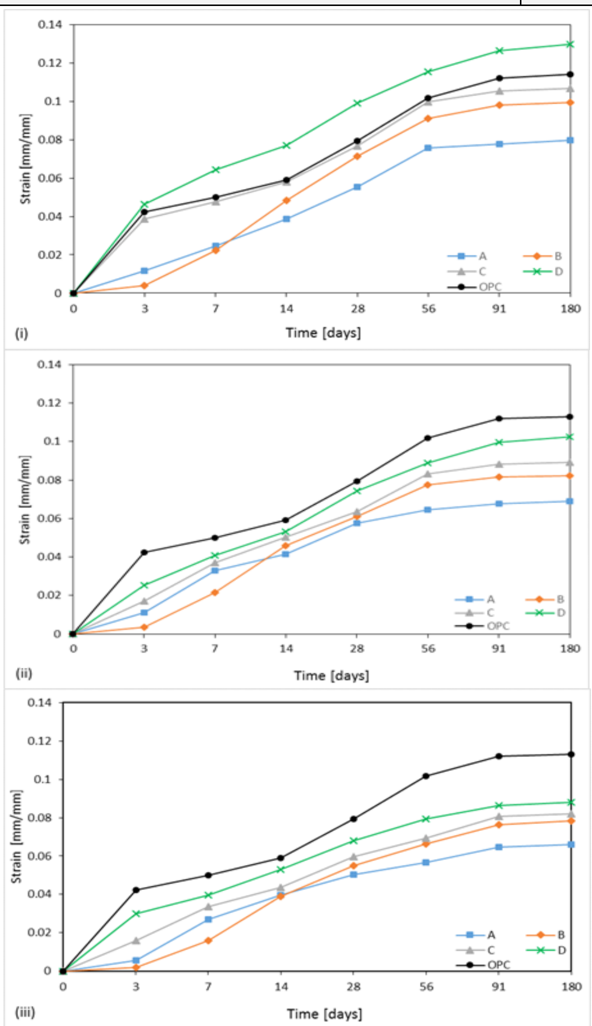
The dry shrinkage results for the RHA mortars mixes under investigation are presented in Figure 1 and Table 4. These results correspond to the average micro deformations (mm mm^{-1}) of two specimens tested for each replacement ratio. In general, the dry shrinkage of all the mixes ranged from 32 to 1016×10^{-4} mm mm^{-1} (RHA-A), 18 to 1052×10^{-4} mm mm^{-1} (RHA-B), 8 to 1242×10^{-4} mm mm^{-1} (RHA-C), 134 to 1391 $\times 10^{-4}$ mm mm^{-1} (RHA-D), compare to 424 to 1143×10^{-4} mm mm^{-1} for OPC mortar, over 180 days. The mixes containing RHA-A and RHA-B had values ranging from 18 to1052×10^{-4} mm/mm, which is considered low for OPC mortar even at 60 % replacement ratio. The RHA-D displayed the highest values of dry shrinkage among all RHA mixes including the OPC mortar reference, at all replacement ratio and curing time.

Table 4. Dry shrinkage strain (mm/mm) of RHA mortars at different replacement ratio compare to OPC mortar at different ages.

Days	5 % RHA mortar				OPC mortar
	A	B	C	D	
3	0.0118	0.004	0.0388	0.0462	0.0424
7	0.0246	0.0224	0.0476	0.0644	0.0500
14	0.0386	0.0482	0.0580	0.0770	0.0590
28	0.0554	0.0714	0.0766	0.0990	0.0794
56	0.0758	0.0912	0.0996	0.1154	0.1004
91	0.0776	0.0980	0.1054	0.1264	0.1120
180	0.0796	0.0995	0.1068	0.1298	0.1143

Days	10 % RHA mortar				
	A	B	C	D	
3	0.0112	0.0034	0.0172	0.0254	
7	0.0328	0.0214	0.0370	0.0408	
14	0.0414	0.0458	0.0502	0.0532	
28	0.0576	0.0612	0.0636	0.0742	
56	0.0646	0.0776	0.0832	0.0890	
91	0.0678	0.0816	0.0882	0.0882	
180	0.0689	0.0823	0.0891	0.1024	
Days	**15 % RHA mortar**				
	A	**B**	**C**	**D**	
3	0.0056	0.0018	0.0158	0.0300	
7	0.0270	0.0158	0.0336	0.0396	
14	0.0396	0.0390	0.0438	0.0530	
28	0.0502	0.0550	0.0598	0.0680	
56	0.0568	0.0662	0.0694	0.0794	
91	0.0646	0.0762	0.0806	0.0862	
180	0.0659	0.0785	0.0819	0.0881	
Days	**20 % RHA mortar**				
	A	**B**	**C**	**D**	
3	0.0148	0.0046	0.0138	0.0178	
7	0.0216	0.0232	0.0298	0.0358	
14	0.0290	0.0362	0.0390	0.0506	
28	0.0484	0.0536	0.0564	0.0660	
56	0.0596	0.0646	0.0670	0.0780	
91	0.0672	0.0700	0.0744	0.0840	
180	0.0685	0.0711	0.0768	0.0852	
Days	**30 % RHA mortar**				
	A	**B**	**C**	**D**	
3	0.0034	0.0032	0.0100	0.0152	
7	0.0284	0.0246	0.0306	0.0400	
14	0.0304	0.0334	0.0362	0.0512	
28	0.0444	0.0484	0.0538	0.0648	
56	0.0624	0.0670	0.0754	0.0788	
91	0.0664	0.0706	0.0808	0.0890	
180	0.0670	0.0723	0.0827	0.0910	

Days	40 % RHA mortar			
	A	B	C	D
3	0.0092	0.0110	0.0008	0.0134
7	0.0330	0.0282	0.0084	0.0406
14	0.0490	0.0464	0.0228	0.0529
28	0.0604	0.0664	0.0462	0.0730
56	0.0794	0.0848	0.0826	0.0966
91	0.0818	0.0868	0.0928	0.1016
180	0.0829	0.0881	0.0937	0.1043
Days	**50 % RHA mortar**			
	A	**B**	**C**	**D**
3	0.0122	0.014	0.0076	0.0176
7	0.0388	0.035	0.018	0.0406
14	0.0590	0.056	0.0322	0.0656
28	0.0770	0.0786	0.0626	0.0856
56	0.0874	0.0892	0.0826	0.1076
91	0.0926	0.0994	0.1018	0.1164
180	0.0939	0.1002	0.1065	0.1198
Days	**60 % RHA mortar**			
	A	**B**	**C**	**D**
3	0.0176	0.0144	0.0116	0.0234
7	0.055	0.0436	0.0312	0.0582
14	0.0644	0.0712	0.053	0.0768
28	0.0832	0.0872	0.0732	0.0944
56	0.0934	0.0972	0.108	0.1176
91	0.0994	0.1014	0.1242	0.1326
180	0.1016	0.1052	0.1267	0.1391



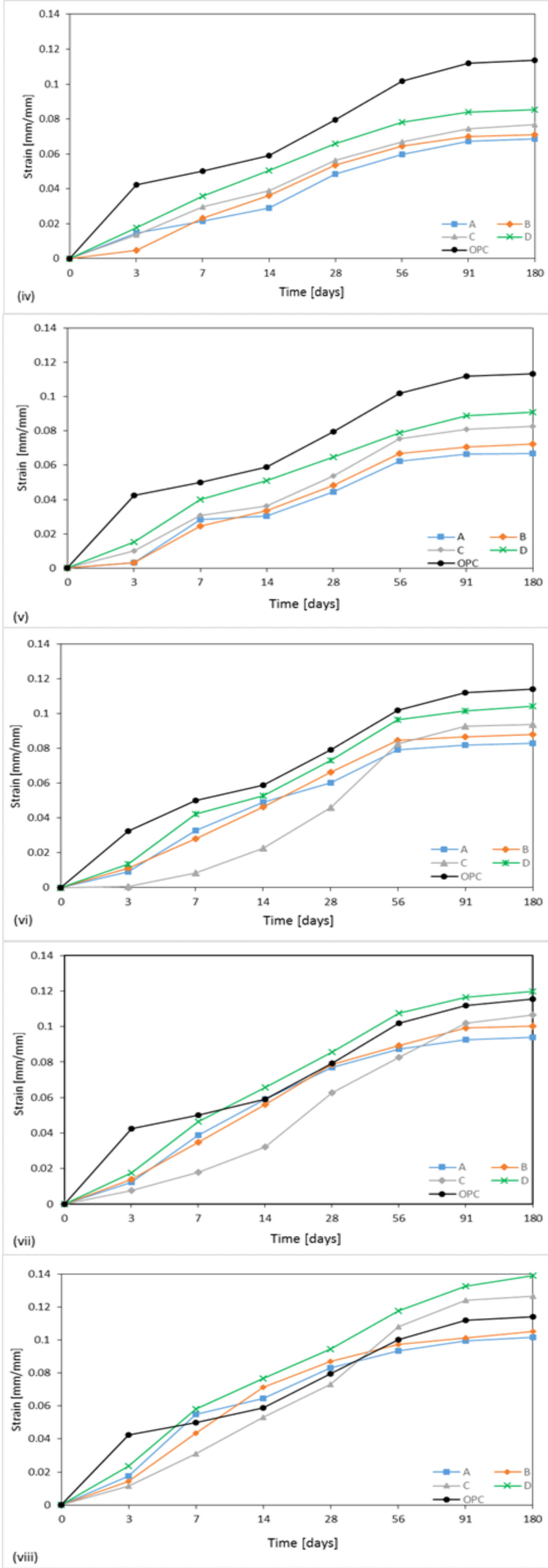


Figure 1. Effect of RHA properties to the replacement ratio on the dry shrinkage of RHA mortars compared to OPC at; (i) 5%, (ii) 10%, (iii) 15%, (iv) 20%, (v) 30%, (vi) 40%, (vii) 50%, and (viii) 60% replacement ratio.

Table 5. Effect of RHA on the dry-shrinkage of mortar at different ages.

RHA %	Strain (mm mm^{-1})						
	RHA-A						
Days →	**3**	**7**	**14**	**28**	**56**	**91**	**180**
5	-0.0118	-0.0246	-0.0386	-0.0554	-0.0758	-0.0776	-0.0796
10	-0.0112	-0.0334	-0.0414	-0.0576	-0.0646	-0.0678	-0.0689
15	-0.0056	-0.0270	-0.0396	-0.0502	-0.0568	-0.0646	-0.0659
20	-0.0148	-0.0216	-0.0290	-0.0484	-0.0596	-0.0652	-0.0685
30	-0.0034	-0.0284	-0.0304	-0.0444	-0.0624	-0.0664	-0.0670
40	-0.0092	-0.0330	-0.0490	-0.0604	-0.0794	-0.0818	-0.0829
50	-0.0122	-0.0388	-0.059	-0.0770	-0.0874	-0.0926	-0.0939
60	-0.0176	-0.0550	-0.0644	-0.0832	-0.0934	-0.0954	-0.1016

RHA %	Strain (mm mm^{-1})						
	RHA-B						
Days →	**3**	**7**	**14**	**28**	**56**	**91**	**180**
5	-0.004	-0.0224	-0.0482	-0.0714	-0.0912	-0.098	-0.0995
10	-0.0034	-0.0214	-0.0458	-0.0612	-0.0776	-0.0816	-0.0823
15	-0.0018	-0.0158	-0.0390	-0.0550	-0.0662	-0.0762	-0.0785
20	-0.0046	-0.0232	-0.0362	-0.0536	-0.0646	-0.0700	-0.0711
30	-0.0032	-0.0246	-0.0334	-0.0484	-0.0670	-0.0706	-0.0723
40	-0.0110	-0.0282	-0.0464	-0.0664	-0.0848	-0.0868	-0.0881
50	-0.0140	-0.0350	-0.0560	-0.0786	-0.0892	-0.0994	-0.1002
60	-0.0144	-0.0436	-0.0712	-0.0872	-0.0972	-0.1004	-0.1052

RHA %	Strain (mm mm^{-1})						
	RHA-C						
Days →	**3**	**7**	**14**	**28**	**56**	**91**	**180**
5	-0.0388	-0.0476	-0.0580	-0.0766	-0.0996	-0.1054	-0.1068
10	-0.0172	-0.0370	-0.0502	-0.0636	-0.0832	-0.0882	-0.0891
15	-0.0158	-0.0336	-0.0438	-0.0598	-0.0694	-0.0806	-0.0819
20	-0.0138	-0.0298	-0.0390	-0.0564	-0.0670	-0.0744	-0.0768
30	-0.0100	-0.0306	-0.0362	-0.0538	-0.0754	-0.0806	-0.0827
40	-0.0008	-0.0086	-0.0228	-0.0462	-0.0806	-0.0928	-0.0937
50	-0.0076	-0.0180	-0.0322	-0.0626	-0.1064	-0.1018	-0.1065
60	-0.0116	-0.0312	-0.0530	-0.0732	-0.1120	-0.1242	-0.1267

RHA %	Strain (mm mm^{-1})						
	RHA-D						
Days →	**3**	**7**	**14**	**28**	**56**	**91**	**180**
5	-0.0462	-0.0644	-0.0770	-0.0990	-0.1154	-0.1264	-0.1298
10	-0.0254	-0.0408	-0.0532	-0.0742	-0.0890	-0.0996	-0.1024
15	-0.0300	-0.0396	-0.0530	-0.0680	-0.0794	-0.0862	-0.0881
20	-0.0178	-0.0358	-0.0506	-0.0660	-0.0780	-0.0840	-0.0852
30	-0.0152	-0.0400	-0.0512	-0.0648	-0.0788	-0.0890	-0.0910
40	-0.0134	-0.0406	-0.0592	-0.0730	-0.0966	-0.1016	-0.1043
50	-0.0176	-0.0424	-0.0656	-0.0856	-0.1076	-0.1164	-0.1198
60	-0.0184	-0.0532	-0.0768	-0.0944	-0.1176	-0.1296	-0.1421

Effect the fineness of RHA particles

Based on the experimental results the RHA mean particles size, amorphous silica percentage are particularly effective on the dry shrinkage of RHA mortars performance. Generally, there is a linear correlation between the particle size distributions to the development of dry shrinkage of RHA mortars which is presented in Table 5 (Figure 1).

Effect of RHA properties on the dry shrinkage of mortar

As shown in Figure 1, there is a general trend on dry shrinkage decreasing with increasing replacement ratio up to 20 %. This can be justified by the pozzolanic and the filler effects.[6] This fact has been reported by other researchers also.[7,8] These results correspond to the average micro deformations (10^{-6} mm/mm) of the two specimens tested for each mix. From data presented in Table 2, it can be noted that RHA-D at 5 % replacement ratio exhibited higher dry shrinkage than that of reference mortar by about 12.25 %. The increases in dry shrinkage strain of RHA-D at 5 %, can be justified by the pozzolanic and the filler effects.[6] Even though, RHA-C consists of entirely amorphous silica, it exhibited lower dry-shrinkage compare to OPC mortar at 5 % replacement ratio. This behaviour of RHA-C specimens can be attributed to the high residual carbon content. On the other hand, the dry shrinkage of RHA mortar specimens was noticeably reduced by the addition of RHA-A and B. Specimens at 180 days showed a reduction in dry shrinkage strain by 30.11 % and 12.64 % compared to OPC. Partial replacement crystalline silica with coarse particles of RHA provides a positive effect on the dry shrinkage of mortar, which is attributed to the filler effect. This correlation was determined for 20% RHA; however, it's same for other RHA replacement ratio. Where, mortar specimens containing RHA-C and D with a particles size of 15.804 and 12.64 μm, exhibited higher dry-shrinkage compare to RHA-A and B with 23.397 and 20.948 μm, respectively. According to Habeeb and Fayyadh[6] RHA with fine particles significantly affected on the dry shrinkage of concrete mixtures containing 20 % RHA, Thus, it can be concluded that the addition of RHA content higher amount of microfine particles to mortar would increase the drying shrinkage.

Conclusions

The drying shrinkage was significantly affected by RHA silica structure and fineness of particles. RHA-D recorded the higher shrinkage value, while RHA-A exhibited lower values than the control, this could be due to the effect of the microfine particles.

The use of the RHA for application in mortar showed excellent performance in drying shrinkage at 60 % RHA-A and B compare to control mortar. Strains due to drying shrinkage are ranged from 1016 to 1391 $\times 10^{-6}$ (mm/mm) at 180 days.

The parameters affecting the dry shrinkage strain are RHA silica structure, size of RHA grain particles and replacement ratio. The effective mean particle size of RHA on mitigating dry shrinkage of RHA mixtures was suggested to be over 20.0 μm, where with coarser particles size less dry shrinkage reported.

Maximum dry shrinkage development registered was in between 3 to 7 days for all RHA mortars mixtures.

The behaviour of RHA dry shrinkage strain is linear concerning the composition of RHA. Where, with a high amount of crystalline silica content and coarser particles size, lower dry shrinkage was obtained as shown with results of RHA-B to A.

As the proportion of replacement ratio increases the dry shrinkage of the mortar decreased up to 15% RHA-A, and 20% RHA-B, C and D, beyond this limitation increased.

A linear relationship is established between compressive strength and dry shrinkage, this correlation is more significant for the dry shrinkage, and it will be more adequate if the shrinkage is measured starting from the setting time. It is shown that there is a strength value for each type of RHA mortar mixtures from which the shrinkage behaviour between blended cement and ordinary cement changes.

According to the literature, there is some debate among the researchers, about the advantageous use of RHA in mortar and concrete in respect of dry shrinkage. However, this study proves the point view of the majority of the researchers about the positive impact of RHA on the decrease of mortar dry shrinkage at the extended period.

References

[1]Xu, Y., Chung, D. D. L., Reducing the drying shrinkage of cement paste by admixture surface treatments, *Cement, Concrete Res.*, **2000**, *30* (*2*), 241-245. https://doi.org/10.1016/S0008-8846(99)00239-2

[2]Park, S. B., Lee, B. I., echanical properties of carbon-®ber-reinforced polymer-impregnated cement composites, *Cement Concrete Compos.*, **1993**, *15* (*3*), 153–163. https://doi.org/10.1016/0958-9465(93)90004-S

[3]De Sensale, G. R., Strength development of concrete with rice-husk ash, *Cement, Concrete Compos.*, **2006**, *28*(2), pp.158-160. https://doi.org/10.1016/j.cemconcomp.2005.09.005

[4]Cezar D. S., *Characteristics of durability of concrete with fly ash and rice husk ash with and without processing*, Master's thesis. Santa Maria: College of Civil Engineering, Federal University of Santa Maria, **2011**, 143.

[5]ASTM, C., 490/C 490 M-09. Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete, **2009**.

[6]Habeeb, G., Fayyadh, M., Rice Husk Ash Concrete: the Effect of RHA Average Particle Size on Mechanical Properties and Drying Shrinkage, *Aust. J. Basic Appl. Sci.*, **2009**, *3*(*3*), 1616-1622.

[7]Zhang, M. H. and Malhotra, M. V., High-performance concrete incorporating rice husk ash as supplementary cementing material, *ACI Mater. J.*, **1996**, *93*(*6*), 629-636.

[8]Chatveera, B., Lertwattanaruk, P., Durability of conventional concretes containing black rice husk ash, *J. Environ. Manage.*, **2011**, *92(1)*, 59-66. doi: 10.1016/j.jenvman.2010.08.007.

Received: 10.05.2018.
Accepted: 13.06.2018.