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Evaluation of Coal Waste Ash and Rice Husk Ash on Properties of Pervious Concrete Pavement

G. Shafabakhsh*, S. Ahmadi

Faculty of Civil Engineering, Semnan University, Semnan, Islamic Republic of Iran

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ABSTRACT

The use of pervious concrete has been significantly considered in recent years. This consideration is due to the properties of pervious concrete in relation to the environmental sustainability that is utilized in the effective management of the runoff from rainfall. Coal extraction and rice husk obtained from milling, produces wastes that have no application and followed by environmental pollution. The purpose of current research is to evaluate the effects of coal waste ash (CWA) and rice husk ash (RHA) and to compare the mechanical properties of pervious concrete pavement with concrete having ash. Therefore, both of these wastes were burned and after that XRF testing it was observed that they have achieved pozzolanic properties. In order to strengthen pozzoli cement, certain amount of CWA and RHA as a cement replacement were added to concrete mixtures. The results indicated that the addition of RHA and CWA improved the mechanical properties of pervious concrete. However, the optimum percentage is dramatically varying. Among these, the effectiveness of CWA is more significant compared to RHA. By increasing the amount of CWA and RHA to the optimum level, the permeability of the pervious concrete had simultaneously decreased. However, beyond the optimum level, it may show inverse respond.

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1. INTRODUCTION

Pervious concrete is made up of an interconnected network of pores so that the porosity percentage is between 15 to 35 percent of the total mixture [1]. Porous and interconnected structure pore allows that water to easily penetrate into it and convert this type of pavement to Eco-friendly pavement materials.

Annual rainfall in most Iranian cities is less than 300mm in average, but due to the semi-arid climate, precipitations often have high intensity and short duration. These types of precipitations obviously cause raising urban floods. If runoff collection system is not effectively designed and operated, the city will face with several problems such as street flood, traffic disturbance, pollution due to flowing polluted runoff and flooding the residential areas during precipitation. Thus, this problem can be solved using pervious concrete technology and it can be used as pavement. There is an increasing interest to use pervious concrete in parking lots, pedestrian and light traffic roads with pavement in layers as gutters in foundation layers of roads and hydraulic structures [2]. In environmental discussions, the open structure of pervious concrete can be used as a filter to trap pollutants such as chemicals and heavy metals [3].

Pervious concrete materials are made up of cement, water, blend of coarse and fine aggregates with 7% coarse aggregate by weight. In general, pervious concrete compressive strength is variable from 3.5 to 28MPa and permeability between 0.2 and 4.5 mm/s [4].

The contact area between the cement paste and the aggregate level is the border area that has an important role in permeability, durability and strength of concrete. The cement paste in contact area has a different micro-structure compared with the inside bulk of the cement paste and it has more porosity and micro cracks [5]. In this paper, RHA and CWA have been used to improve this contact area.

*Corresponding Author's Email: shafabakhsh@semnan.ac.ir (G. Shafabakhsh)

One of the concerns is millions of tons of mineral and industrial waste which are stored around the world and cause many problems such as serious environmental problems [6]. Taking advantage of this waste material as an effective additive in mixtures can have a major impact on the cost savings of the pavement in addition to conserving natural resources and the environment. Due to the depletion of natural resources and increasing the building and road construction activities and energy saving and environmental aspects, researchers sought to find an adequate replacement for materials which are used in the construction of roads [7, 8].

Solid waste materials are found in urban and rural areas. These wastes can be agricultural or industrial. Agricultural waste materials have adverse effects on the environment. However, using these materials has advantages; they improve the thermal properties of the concrete [9, 10]. Also, using these materials directly affects costs, in addition to improving the properties of concrete.

Rice husk is a natural coating that is formed around a grain of rice during its growth. After harvesting the rice and transition to the factory, this husk would not have any application and it is considered as a waste material. RHA can be used as supplementary cementitious materials. It contains 85-90 percent amorphous silica [9].

Zain et al. have proposed a new way to burn the rice husk. In this method the rice husk is heated in a furnace from 10 to 700 °C for 6 hours. After that, it is allowed to cool by placing these materials at room temperature [11]. RHA is very fine -from 5 to 10 micrometers [12]. Increasing the strength of concrete with supplementary cementitious materials such as RHA is a very important issue because the compressive strength of concrete plays an important role in designing roads and concrete structures [13]. Several studies have been done in the field of using RHA in concrete. In these studies, the optimal amount of RHA for increasing the compressive strength of the concrete is 5 to 20% of the cement's weight [12, 14, 15]. This wide difference depend greatly on how it is burnt which, has a direct impact on pozzolanic properties.

Figure 1. Deposit wastes in the central Alborz coal washing factory

One of the world's known fossil energy sources is coal. Coal mining causes producing wastes which has impact on the environment and directly or indirectly causes pollution and damages the environment. Until now, coal waste has been used in hot mix asphalt, cement mixture, stabilized soil and block concrete pavements. Coal waste powder with pozzolanic properties and silica and alumina can have properties similar to F-type pozzolan and improve the performance of the pavement [16]. Friasa et al. have used three types of coal waste with different chemical compounds as part of the cement in the concrete mixture. The results showed that the used amount increases 7, 28, and 90 days compressive strength [17]. Inuthia and Nidzam have used coal waste and other material to stabilize the base and sub-base layers. Their results indicated that when coal waste and limestone are used, they do not have any impact on the base and sub-base properties. However, the combination of coal waste with cement and slag or a material that has much silica dramatically improves the strength of the base and sub-base layers [18]. Mazandaran Central Alborz coal mine located in Savadkooh is one of the oldest mines with probable reserves of 557 million tons. Currently, there are more than 2 million tons of deposit coal waste and frequent problems have arisen from their accumulation.

The annual coal production in the country is 310 million tons. After using coal in various consumptions, a large amount of them are landfilled or deposited as waste. Using coal waste in terms of cost is very low. On the other hand, storing these wastes has caused many problems for the environment and the region. In Figure 1, deposit wastes in the central Alborz coal washing factory is shown.

As can be seen in Figure 1, waste deposit has occupied a lot of space around the factory and the surrounding roads which caused many problems. Doulati Ardejani et al. have studied the effect of coal waste on the environment. According to their results, this material causes corrosion, leakage of pollution to groundwater, spread of dust, air pollution and limitation of usable space [19]. The problem of pollution in coal mines is from pyrite oxidation. When pyrite and materials containing iron are exposed to water or air or both, they undergo a rapid oxidation which leads to production of acidic water. Pollution from acid mine drainage (AMD) is the most important water pollutants around mines which include ferrous sulfate and other substances that can pollute water sources [20]. As mentioned above, considering the importance and effectiveness of contact area and also, the lack of natural resources, the purpose of this paper is using waste material of CWA and RHA for economic saving and reduction of environmental problems and improving the mechanical properties of existing concrete pavements. Finally, the results of the experiments were analyzed with SAS 9.1 statistically.

The statistic design is the randomized block design and averages were compared by use of LSD at 5% level.

2. LABORATORY PLAN

2. 1. Material Properties In the present study, the size of coarse aggregates varied from 2.36 to 12.5 mm. Consuming sand passed through the 4.75 mm sieve which has an equivalent of equivalent value (SE = 80%). Considering ASTM C 33 curves for coarse and fine aggregates of present experiment. Also Portland cement type 2 was used. Physical and chemical properties of this type of cement are given in Table 1.

- Initially, rice husk was burned in a furnace in the open air for 2 hours. The black color of the furnace products shows high percentage of carbon that reduces its pozzolanic properties. Then, the obtained product is transferred to an electric oven with the ability to discharge carbon dioxide and at this stage, it is cold for one hour to room temperature. This leads to an increase in specific surface and the pozzolanic property of RHA [21]. Information about chemical and physical properties of RHA is given in Table 1.

- The amount of unburned carbon especially in the cement used in mixed concrete is one of the features that the researchers have noticed. Although, the harmful effects of this substance yet is not proven in concrete; in contraryuse of such material has improved the cement's property, it may acts as a passive filler [22]. In this study, coal waste was burned in order to reduce the percentage of unburned carbon and increase the pozzolanic compounds. ASTM D7348–13 test is related to analysis of coal samples was used to determine the temperature of the burning coal waste in order to reduce the amount of carbon [23]. The coal waste was burned at two temperatures 700 and 900°C for 4 hours in special furnaces and then, the amount of loss on ignition (LOI) was measured for both of ashes. Naturally, with increasing temperature, the produced ash had less LOI. But, since LOI changes in the temperatures above 700°C is not much noticeable, 700°C is determined as the burning temperature of CWP. Figure 2 shows the residual coal after burning and moreover information about chemical and physical properties of CWA summarized in Table 1. The amount of unburned carbon in coal waste powder was 40.96 percent that after burning at a temperature of 700°C, it decreased to 3.66 percent. Also, the specific gravity of the consumed CWA is 2.6 g/cm^3.

2. 2. Test Method In this study, the compressive and tensile strength tests were carried out for a concrete cylindrical sample with the diameter of 150 mm and height of 300 mm considering the ASTM C39 and ASTM C496 standard, respectively. Flexural strength was conducted for prismatic beams under third point loading with dimensions of beams 100×100×500 mm through the use of the ASTM C78 standard. Figure 3 depicts concrete beam under third point loading.

The weight difference between immersion and dry sample weight is calculated to measure the porosity of test samples [24]. Initially, the sample is kept in an oven for 24 hours at 105 °C temperature. W_2 is reached by weighing the dry weight. Then, the dried sample is weighted in water and immersion weight W_1 is reached. Then, the porosity of the sample is calculated using Equation (1). The average value of the test results was reported for three cylindrical samples with the diameter and height of 100mm as the porosity percentage.

TABLE 1. Physical and chemical properties of cement, RHA and CWA

Chemical Analyses	Weight (%)		
	Cement	**RHA**	**CWA**
SiO_2	21.1	86.02	50.9
Al_2O_3	4.37	0.36	27.87
Fe_2O_3	3.88	0.16	4.73
MgO	1.56	0.39	2.27
CaO	63.33	1.12	1.59
L.O.I	-	-	3.66
Physical properties			
Specific gravity	3.10	2.6	2.1
Specific surface area (cm^2/g)	3000	-	3500

Figure 2. Burned coal waste (CWA)

Figure 3. concrete beam under third point loading for flexural strength test

$$P = (1 - (\frac{W_2 - W_1}{Vol \times \rho w})) \times 100 \quad (1)$$

where P is the total porosity, %; W_1 is the weight under water, kg; W_2 is the oven dry weight, kg; Vol is the volume of sample, cm^3; ρw the density of water at 21 ºC, kg/cm^3.

The average permeability coefficient is calculated according to Equation (2) and is based on the Darcy's law and the assumption of layer stream [25]. The average results of three cylindrical with the diameter and height of 100mm is reported as the permeability coefficient.

$$k = \frac{aL}{At} \ln(\frac{h_1}{h_2}) \quad (2)$$

where k is the coefficient of permeability, cm/s; α the cross sectional area of the standpipe, cm^2; L the length of sample, cm; A the cross-sectional area of specimen, cm^2; t the time in seconds from h_1 to h_2; h_1 the initial water level, cm and h_2 is the final water level, cm.

2. 3. Concrete Mix Design In the present study, twelve mix designs were used which obtained according to code ACI211.3R-24 [26]. Firstly, impact of CWA on pervious concrete was investigated and then the effect of RHA was reported. Mix design series A and B include 5, 10, 15, and 20 percent of CWA and 2, 4, 6, 8, 10 and 12 percent RHA, respectively, which were replaced by cement in mix design. Details for mix design are given in Table 2.

According to Table 1, the specific surface of RHA is significantly higher than cement. For this reason, it has led to a sharp decline in the performance of concrete which needs more water to overcome such phenomena. Given that the concrete performance had no changes, the amount of super-plasticizers should be increased. Gastaldin et al. [13] has evaluated the morphology of RHA using microscopic images. The results show that RHA had many forms and porous surfaces that these factors caused that the mix absorbs more water and the slump and performance of concrete were reduced [13]. The mentioned factors besides increasing the amounts of RHA from 2 to 12% showed that the amount of super-plasticizer increased.

3. ANALYSIS OF EXPERIMENTAL RESULTS

3. 1. Compressive Strength By examining the hardened concrete section, two phases were easily recognizable: aggregate phase with different sizes and shapes, cement paste phase, and finally the third phase is the transition zone. The transition zone showed the intersection of coarse aggregate and hardened paste. The transition zone was in the form of a thin shell around the large aggregates. Usually, that was weaker than a thin shell around the large aggregates and as a result, that had more important influence on the mechanical properties of concrete, despite its size [27]. In the pervious concrete without additives, generally, the failure of the concrete becomes hardened at the surface of the paste or the transition zone occurred between paste and aggregate [28].

TABLE 2. Details of mix design

MIX No.	Series	Cem.	Additive (%)		Gra.	Sand	Water	SP
1	A	340	-		1395	105	116	-
2		323	CWA	5	1395	105	116	2
3		306		10	1395	105	116	3
4		289		15	1395	105	116	4
5		272		20	1395	105	116	5
6	B	340	-		1395	105	116	-
7		333	RHA	2	1395	105	116	1
8		326		4	1395	105	116	2
9		319		6	1395	105	116	3
10		312		8	1395	105	116	4
11		306		10	1395	105	116	5
12		299		12	1395	105	116	6

By increasing the age of concrete, it is possible that the transition zone to be equal or even greater than the strength of cement paste. These can be expressed in such a form that in the case of presenting Pozzolanic material, hydrated calcium silicate is formed. Thus, it crystallizes the new products in the pores of the transition zone; which is under the chemical reactions between cementpaste and aggregates [29].

The reason of increasing the strength of pozzolan can be the filling, condensation and filling effect of the cement paste. Pozzolanic material is composed of silica materials that when they are combined with calcium hydroxide they found cement material characteristics. According to the above contents, it is tried in this study to strengthen the transition zone between paste and aggregate using RHA and CWA pozzolans and consequently, increase the mechanical properties of concrete pavement.

In Figure 4, the effect of RHA and CWA pozzolans on the compressive strength of concrete is shown using the results of series A and B. As data are illustrated in Figure 4, the compressive strength of concrete containing RHA has increased by 41 percent than the control concrete and also, the amount of 8% of the RHA was considered as optimum level. From the results related to CWA in Figure 4 can be seen that 10% of CWA increased 80 percent compared to the control concrete.

Accordingly, from the above it can be concluded that RHA and CWA both were considered as pozzolan, by reducing the amount of calcium hydroxide in the transition zone, the strength in this area have increased so that according to the results, the effects of CWA on concrete was much better than RHA. Nevertheless, both materials have created a significant increase in compressive strength of pervious concrete.

Table 3 shows the variance analysis of statistical design of compressive strength of concrete and also comparison between treats using LSD method with level of 5%.

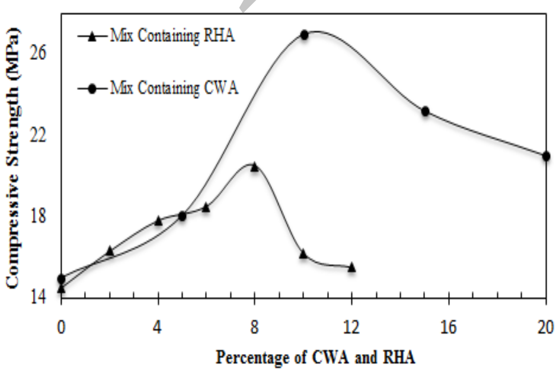

Figure 4. The compressive strength of concrete containing RHA and CWA

TABLE 3. Results of statistical design for variance analysis for compressive strength

Mix No.	Source	DF	Sum of Squares	Mean Square	F Value	R^2
Series A	Treat	4	230.683	57.67	116.9	0.98
	Block	2	5.695	2.847	5.77	
	Error	8	3.946	0.493	-	
	Correct Total	14	240.325	-	-	
Series B	Treat	6	55.378	13.844	15.69	0.88
	Block	2	0.366	0.183	0.21	
	Error	10	7.059	0.882	-	
	Correct Total	16	62.804	-	-	

According to Table 3, it can be concluded that F-value for treatment and block for the planss of A and B is significant at the level of 1%. This shows that there is a significant difference between treatments or the mixing plans. Also, according to the one tail changes of RHA from 2 to 12 percent and CWA i.e. from 5 to 20 percent, blocking is suitable for the plan and other words, by reducing the degree of freedom the test accuracy is increased. Another issue that must be addressed is the coefficient of variation which was not very much in the A series plan than B series plan of the average of CWA. Also, about the R-square of the series A and B, it can be said that series A has higher accuracy than series B. It is important to note that these changes can be fitted with a low accuracy with a line.

3. 2. Tensile Strength

The results of tensile strength of tests for different 5 percent of CWA and different 7 percent of RHA are shown in Figure 5. As can be seen from Figure 5, the tensile strength range is between 1.3 to 2.52 MPa. Similar the compressive strength by increasing the replacement rate of cement with RHA and CWA, initially the tensile strength increases and then, decreases so that their difference is in the optimal amount of these materials.

As can be seen, the maximum amount of tensile strength is related to the sample 3 which includes 10% of CWA and the minimum amount is related to the control sample. According to results, the 8 percent of the RHA had 42 percent increase than the control concrete, while, the 10 percent of CWA had 94 percent increase than the control concrete. It is important to note that probably due to the filling and strengthen the cement paste and also, formation of hydrated calcium silicate by Pozzolanic material and consequently, crystallization of new products in the pores of the transition zone, increasing in the tensile strength of concrete containing pozzolan of RHA and CWA compared to the control concrete can be seen. Similar to compressive strength, the sample containing the CWA has a much better effect on the pervious concrete which causes the tensile strength almost double. As can be seen in Figure 5, after the optimal range, by increasing the amount of pozzolan of RHA and CWA, the amount of tensile strength decreases due to reduce the performance and lack of existing the needed water.

Table 4 shows the variance analysis of statistical design of tensile strength of pervious concrete and also comparison between treats using LSD method with level of 5%. As is clear from Table 4, the variance analysis of a complete block design is indicated. In this table, the F-value for treatment and block for Series A and B was significant at 1% which shows that there are significant differences between treatments. Also, due to the one tail changes of CWA and RHA, blocking is also significant. As can be seen, the R-square for series A is 0.97 which shows that there is a linear relationship between data. In other words, this indicates that a linear function can be fitted in the series B these changes are less linear according to the obtained result.

3. 3. Flexural Strength

The design criteria for the concrete pavements is flexural strength which is very important. For example, the least 28 days flexural strength for the pavement of an airport is 4.1MPa [30]. Based on the conducted studies the acceptable limits of road pavements is from 3.44 to 27.56 MPa for compressive strength and 1.03 to 3.78MPa for flexural strength [31].

Figure 6 show the flexural strength behavior containing CWA and RHA. As can be seen, by increasing the amount of pozzolan of CWA and RHA respectively, to 10 and 8%, the flexural strength is increased, but using more of them reduces the flexural strength. According to results, A3 plan had 61 percent increasing than the control concrete and plan 10 in series B had 29 percent increasing than the control concrete. Based on the results, the most flexural strength is related to plan 3 and its amount is 3.7MPa and the least amount is 2.2 MPa so that the optimum amount of CWA and RHA is considered 10 and 8 percent, respectively.

The reason for increasing the flexural strength of the pervious concrete can be stated that the CWA and RHA having pozzolanic properties and having silica and alumina can increase adhesion between matrix of cement and aggregates. Among the researchers who have worked in this field, De Sensale [12] has achieved the increasing trend of the flexural strength in the normal concrete using RHA which is corresponded with the obtained results in similar study [17]. Table 5 shows the variance analysis of statistical design of flexure strength of pervious concrete and also comparison between treats using the LSD method with a level of 5%.

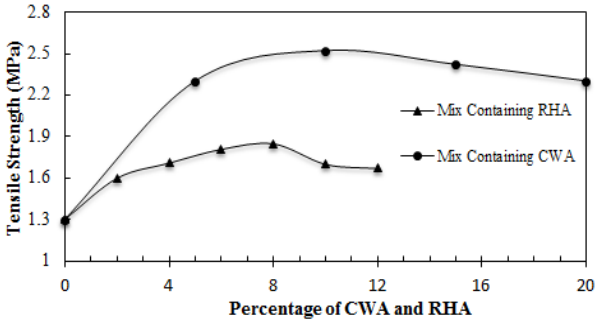

Figure 5. The Tensile strength of concrete containing CWA and RHA

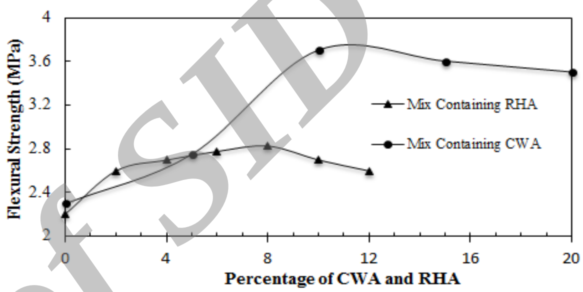

Figure 6. The flexural strength of concrete containing CWA and RHA

TABLE 4. Results of statistical design for variance analysis for tensile strength

Mix No.	Source	DF	Sum of Squares	Mean Square	F Value	R^2
Ser. A	Treat	4	2.984	0.746	69.06	0.97
	Block	2	0.016	0.008	0.76	
	Error	8	0.086	0.010	-	
	Correct Total	14	3.087	-	-	
Ser. B	Treat	6	0.566	0.141	17.38	0.89
	Block	2	0.006	0.003	0.4	
	Error	10	0.065	0.008	-	
	Correct Total	16	0.637	-	-	

Considering Table 5, it can be seen that the F-value for treatment and block is significant that shows there is a significant difference between the mixing plans for the treatment and the differences between blocks are proven for the block. The blocking factor as was mentioned is the percentages of RHA and CWA and the importance of this work can be found here. Relatively high coefficient of variation (greater than 3) represents the difference of high average for percentages of RHA and CWA which were resulted for flexural strength. Also, the R-square less than 1 indicates that series B is less linear than series A and about the obtained results it can be said that series A can be fitted with a line with a low accuracy.

TABLE 5. Results of statistical design for variance analysis for flexural strength

Mix No.	Source	DF	Sum of Squares	Mean Square	F Value	R^2
Ser. A	Treat	4	98.09	24.522	63.26	0.97
	Block	2	8.965	4.482	11.56	
	Error	8	3.101	0.387	-	
	Correct Total	14	110.157	-	-	
Ser. B	Treat	6	42.189	10.547	30.24	0.94
	Block	2	0.289	0.144	0.41	
	Error	10	2.790	0.348	-	
	Correct Total	16	45.269	-	-	

TABLE 6. Results of statistical design for variance analysis of porosity

Mix No.	Source	DF	Sum of Squares	Mean Square	F Value	R^2
Ser. A	Treat	4	3.784	0.946	55.58	0.97
	Block	2	0.197	0.098	5.79	
	Error	8	0.136	0.017	-	
	Correct Total	14	4.117	-	-	
Ser. B	Treat	6	0.612	0.153	9.36	0.82
	Block	2	0.002	0.001	0.07	
	Error	10	0.13	0.0163	-	
	Correct Total	16	0.571	-	-	

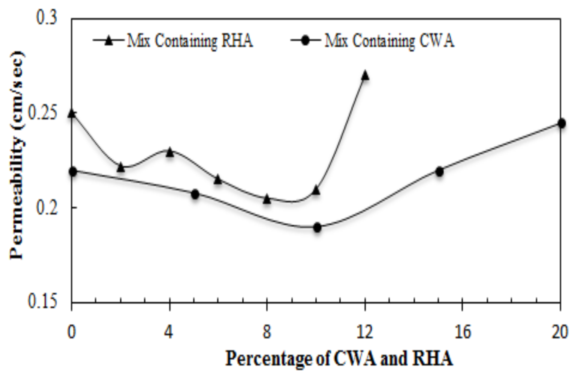

Figure 7. The permeability of concrete containing CWA and RHA

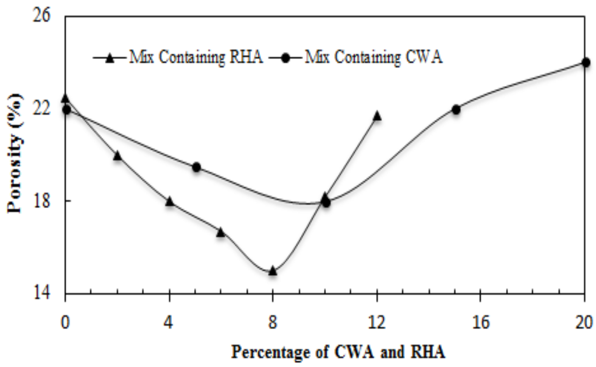

Figure 8. The porosity of concrete containing CWA and RHA

3. 4. Permeability and Porosity The drainage speed of pervious concrete pavement changes with the particle size and density of the mixture. But, generally, the conventional speed of drainage in pervious concrete is between 1.35 to 12.2 mm/s [4]. The results of permeability and porosity tests for different 5 percent of CWA and different 7 percent of RHA are shown in Figures 7 and 8.

As can be seen in Figures 7 and 8, the permeability range is between 0.19 to 0.27 cm/s and porosity is between 15 and 24 percent. According to the results, by increasing the replacement amount of cement by RHA and CWA, the amounts of porosity and permeability are decreased to an optimal value of this two material and in continue, they are increased. It is obvious that the permeability and porosity have a direct relationship with each other so that by increasing the amount of porosity, the amount of permeability coefficient increases [4].

As previously mentioned, by increasing the additives the thickness of the transition area decreases and it reduces the amount of porosity and permeability and increases the mechanical properties. Of course, this decreasing is to the extent that it reaches the optimal point. From this point onwards, as can be seen, the mechanical properties are reduced and it causes increasing the amount of permeability and porosity.

Table 6 show the variance analysis of statistical design of porosity of pervious concrete and also comparison between treats using the LSD method with a level of 5%.

Table 6 shows the results of the analysis of variance for porosity. As can be seen, although the difference between treatments was significant at the 1% level, but, the obtained F-value in the table is not a large number despite a parameter like the compressive strength and this shows the proximity of the obtained values for different treatments. Another issue that is very important is the coefficient of variation that these values in both series A and B are less than 3 and this represents that the Standard deviation is not high.

4. CONCLUSION

In this paper, usage of RHA and CWA in pervious concrete was examined. With respect to experimental data, the overall results of this study could be listed as follows:

1. As a general conclusion, it can be expressed that one of the best solutions to reduce the environmental pollution and dramatic improve of pervious concrete pavement is using CWA and RHA.
2. Permeability of mix designs (A and B series) showed that permeability was between 0.19 to 0.27 cm/s, which is high enough to be used as a drainage layer in the base layer or the surface layer of pavement roads .
3. Acquisition trend of compressive, tensile, and flexural strength in both (series A, B) are the same and it is in such a way that it increases to the optimal point with a steep slope and then, it decreases with a mild slope from that point onwards.
4. Optimum percentage for concrete with RHA additive was 8% while the figure for concrete with CWA was 10% .
5. For an optimum percentage of RHA replacement (8%), the compressive strength, tensile strength and flexural strength increases by 41, 42 and 29%, respectively.
6. For an optimum percentage of CWA replacement (10%), the compressive strength, tensile strength and flexural strength increases by 80, 94 and 61%, respectively.
7. By increasing the amount of CWA and RHA in the previous concrete, its permeability decreases, and its mechanical properties increased.

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Evaluation of Coal Waste Ash and Rice Husk Ash on Properties of Pervious Concrete Pavement

G. Shafabakhsh, S. Ahmadi

Faculty of Civil Engineering, Semnan University, Semnan, Islamic Republic of Iran

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چکیده

استفاده از بتن متخلخل به طور قابل توجهی در چند سال اخیر مورد توجه قرار گرفته است. این توجه به دلیل ویژگی های بتن متخلخل در رابطه با محیط زیست پایدار در مورد مدیریت موثر رواناب ناشی از بارندگی مورد توجه می باشد. استخراج زغال سنگ و پوسته برنج بدست آمده از شالیکوبی، پسماندهایی را تولید می کند که هیچ کاربردی ندارد. هدف از این پژوهش بررسی اثر ضایعات زغال سنگ سوخته و خاکستر پوسته برنج و مقایسه بین این دو بر خصوصیات مکانیکی روسازی بتنی متخلخل می باشد. بنابراین در این مطالعه هر دوی این مواد پسماند سوزانده شده و بعد از انجام آزمایشاتXRF مشخص گردیدکه هر این مواد به عنوان پوزولان محسوب می شوند. در مطالعه حاضر به منظور تقویت خمیر سیمان از پودر ضایعاتی زغال سنگ سوخته و خاکستر پوسته برنج به عنوان جایگزین بخشی از سیمان در ترکیبات بتن استفاده شده است. نتایج نشان می‌دهد اضافه شدن پودر ضایعاتی زغال سنگ سوخته و خاکستر پوسته برنج سبب بهبود خصوصیات مکانیکی بتن متخلخل می شوند این در حالی است که محدوده درصد بهینه آنها متغیر می‌باشد. در این بین اثر پودر ضایعاتی زغال سنگ سوخته بسیار چشمگیرتر از خاکستر پوسته برنج بوده است و از طرف دیگر با افزایش مقدار پوزولان پودر ضایعاتی زغال سنگ سوخته وخاکستر پوسته برنج تا مقدار بهینه نفوذپذیری بتن متخلخل کاهش و در ادامه افزایش می یابد.

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