



Assessment of Environmental Impact and Formation Factor for Triple Blend Concrete

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ABSTRACT

The assessment of environmental impact on concrete is an important aspect for its durability. The use of supplementary cementitious materials (SCMs) in the concrete can be enhanced the durability. This makes concrete sustainable and reduced environmental issues. In this research paper illustrate the experimental study on the performance of triple blend concrete made up of fly ash (FA) and rice husk ash (RHA) along with ordinary Portland cement (OPC). The current research the concrete composition was used as 20, 30 and 40% cement replacement by FA and RHA. The durability properties such as ultrasonic pulse velocity (UPV), electrical resistivity (ER), water absorption and carbonation depth of triple blend concrete were determined, and for microstructure performance formation factor and Scanning Electron Microscope (SEM) were performed. The improvement in durability was observed up to 40% replacement of cement. The durability of concrete improves with increase in formation factor. The SEM images proved the improvement in particle packing of concrete.

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INTRODUCTION

The demand of durable and sustainable concrete is increasing in construction industry. To achieve these requirements the use of different materials are necessary. The use of supplementary cementations material (SCM) along with cement can be enhancing the durability of concrete. Now days, there are various types of SCM freely available which is produced form industrial and agricultural. Some of them are pozzolanic in nature such as fly ash, slag, silica fume, and rice husk ash and its utilization needed otherwise it will pollutes the land, water and air [1]. The durability of concrete were attained without increasing its cost by incorporation of SCM as partial cement replacement [2, 3]. The FA is produced from power plant. The FA mostly used in concrete as pozzolanic SCM [4]. In case of binary mix the workability and durability of concrete can be increased by addition of FA [5, 6]. But the shortcoming was the addition of FA the depth of carbonation also increased in FA concrete [7, 8], and the drop in concrete compressive strength at the early age over control concrete [9, 10]. The rice husk is an agricultural byproduct produced in huge quantity in India. The burning of husk at (500°C to 700°C) control temperature produced ash with amorphous silica content [3]. The use of RHA shows decrease in workability of the concrete because of rough surface [11]. But improvement shows in durability because of existence of reactive silica in RHA [12-16]. Hence it enhances the life of

concrete structure [17, 18]. The improvement shown in the strength and concrete durability with the addition of FA and RHA along with cement [2, 19]. The reason behind the triple blend concrete is, it improved the microstructure of concrete due to different particle size create dense particle packing. Hence by using particle packing density approach sustainable and durable concrete can be achieved [20]. Less research was found in the study of particle packing of cementitious material [21, 22]. This fundamental of particle packing used in this research work, by using two types of the binder as FA and RHA finer along with OPC. The average particle size at D10 were found that 8 μ m for ordinary Portland cement, 1 μ m for type-1 RHA, 2 μ m for type-2 RHA, 4 μ m for type-3 RHA and 5 μ m for FA particles. The previous study on cement paste [23] and mortar [19] was reported that the particle packing increased the strength and durability of triple blend concrete than control concrete. The present research is aimed to produce sustainable and durable triple blend concrete by using FA and RHA along with OPC.

MATERIAL AND METHOD

In the present research following materials was used as water, cement, river sand, 20mm maximum nominal size of coarse aggregate, FA and RHA. The physical and chemical properties of OPC were conformed from IS 8112-2013 [24].

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The properties of fine aggregate were conformed from IS: 2386-1963 (part-III) and IS 383-2016. The grading of fine aggregate and coarse aggregate were conforming to Zone-II with specific gravity 2.56, 2.62 and 2.64, respectively. The FA was collected from Bhilai, Chhattisgarh, India. The three types of amorphous RHA (Chhattisgarh-RHA(1), Odisha-RHA(2) and Maharashtra-RHA(3) states) were used as another SCM in this research work having greater than 90% of silica content. It was collected from a local vendor. The details of chemical properties of OPC, FA and RHA are shown in Table 1. The specific gravity of OPC, FA, RHA(1), RHA(2), and RHA(3) are 3.14, 2.2, 2.5, 2.4 and 2.36, respectively. The specific surface area of OPC, FA and RHA 372.7 m²/kg, 456.8 m²/kg, 612 m²/kg, 599.9 m²/kg and 580.7 m²/kg, respectively. The polycarboxylate-based super-plasticizer with a specific gravity of 1.2 was used to provide the water drop up to 20% without affecting the workability.

Triple blend of concrete mix is prepared with 0.35 water-cement ratio. The concrete mixes with various ingredients were established for selecting a slump of 55 to 75mm range. The concrete mix design prepared with concerned to IS:10262-2009 [25]. The quantity of RHA, fine aggregate, coarse aggregate, water and chemical admixture 48.2 kg/m³, 626 kg/m³, 1205 kg/m³, 166 kg/m³ and 2.63 kg/m³ were used. The detailed description and designation of blended concrete are tabulated in Table 2. The triple blend concrete mix is represented by (C80-1R10-F10) that means 80% OPC content, 10% type-1RHA and 10% FA, respectively. The variation of FA in the concrete mix was 10%, 20% and 30%. For concrete preparation weight batching was used for all the ingredients of concrete. The concrete mixing was done by laboratory pan mixture for mixing all ingredients. It was mixed for 2 to 4 minutes up to getting a uniform colored and homogeneous concrete. And by observing it insured that all surface of aggregate were coated with binder paste uniformly. At last concrete mix were removed and placed in a tray for slump test and casting of various mold. The UPV was used to study the quality of concrete such as uniformity, absence of internal flaws, cracks, and segregation. Ultrasonic pulse velocity test conforming to IS 13311 (part I): 1992 [26] guidelines. As per the standard guidelines the pulse velocity value above the 4.5 km/s is considers as the excellent quality of concrete. The UPV test was performed for 7, 28, 56 and 90 days cured specimens. The electrical resistivity test conducted for concrete to know the quality of concrete in the form of the severity of the rate of corrosion in concrete. The test was conforming to ASTM C-1760-12 [27, 28]. The absorption defines the penetration of liquid by capillary forces which allow the liquid in concrete through the pores. The water absorption test was conforming to ASTM-C 642-13 [29]. The

samples were placed in the carbonation chamber for 28 days. The dose of carbon dioxide (CO₂) was kept constant at 5%, temperature 35°C and 70% humidity. 28 days cured specimens were tested. For carbonated area phenolphtheline solution as indicator sprayed on the beaked surface of specimen. The color of the surface changed in pink, indicated that the area was not affected by carbonation. And the depth of the affected area was measured. The microstructure analysis of concrete was conducted by the Scanning Electron Microscope test (SEM) [30] for all type of concrete mix. The specimens were prepared in size of 1cm x 1cm x 1cm with polished surface. The specimens were coated by gold for getting clear image.

RESULTS AND DISCUSSION

Ultrasonic pulse velocity

In the triple blend concrete, SCM were used for making concrete durable and sustainable. The combined effects of FA and RHA on the durability of concrete are discussed in this section. The UPV values were observed at 7 days and 28 days. The triple blend concrete mix of 80C1R10F10 was observed increased in UPV values by 5.13% and 5.33%, for 70C1R10F20 triple blend concrete mix was observed the increased in UPV values by 6.81% and 7.62%, for 60C1R10F30 triple blend concrete mix was observed the increase in UPV values by 7.96% and 8.80% with respect to control concrete. Again the UPV value increase at 56 days and 90 days for 80C1R10F10 mix by 6.75% and 7.00%, for 70C1R10F20 mix by 8.08% and 8.55%, for 60C1R10F30 mix by 9.66% and 9.75% with respect to control concrete. Whereas, increased in the UPV values at (7, 28, 56, and 90 days) for triple blend concrete for 10% type-2 RHA and 10% FA as cement replacement was increase by 2.24%, 2.60%, 4.16% and 5.75%, for 20% FA as cement replacement the UPV value increased by 3.51%, 3.68%, 5.09% and 6.46% than control concrete mix. And for 30% FA as cement replacement the UPV value increased by 5.13%, 5.33%, 5.76% and 7.38% than reference concrete mix. Similarly for 10% type-3 RHA and 10% FA as cement replacement were increased by 1.41%, 1.79%, 2.69% and 3.29%, for 20% FA as cement replacement the UPV value increased by 2.02%, 2.47%, 3.62% and 4.86% than control concrete mix. For 30% FA as cement replacement the UPV value increased by 2.98%, 3.14%, 4.54% and 6.48% than reference concrete mix. This was due to increased in cement hydration product, which was formed with the presence of silica in RHA, silica and alumina content in FA. It improves the microstructure of concrete, interfacial transition zone (ITZ), particle packing and hence it helps increase the durability of concrete. The

TABLE 1. Chemical property of raw materials

Contents	Mass Content (%)						
	SiO ₂	CaO	Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O	Na ₂ O
OPC	15.7	68.51	4.65	3.76	1.66	2.35	0.37
FA	63.78	1.12	24.44	5.01	0.48	2.46	0.11
RHA(1)	92.45	1.94	0.79	0.74	0.37	0.22	0.41
RHA(2)	90.49	1.71	0.68	0.52	0.32	1.03	0.12
RHA(3)	86.39	1.65	0.51	0.66	0.45	1.11	0.21

TABLE 2. Mix proportion of concrete (kg/m³)

Mix Designation	Cement	FA
C100-R0-F0	438	0
C80-1R10-F10	385.42	48.2
C70-1R10-F20	337.24	96.36
C60-1R10-F30	289.06	144.54
C80-2R10-F10	385.42	48.2
C70-2R10-F20	337.24	96.36
C60-2R10-F30	289.06	144.54
C80-3R10-F10	385.42	48.2
C70-3R10-F20	337.24	96.36
C60-3R10-F30	289.06	144.54

details of the test results were shown in Figure 1. The triple blend concrete made with combination of type-1, type-2 and type-3 RHA with FA the higher values of UPV was observed for each percentage of cement replacement at all ages. It was also noticed that UPV value was increased with increase in cement replacement in comparison to control concrete. All the concrete mixes samples UPV values attained above the 4.5 km/sec. From the UPV, test results were shown that the triple blend cement concrete obtained had excellent durability for all concrete mix as per IS code. It means the dense microstructure of concrete had formed, resulting in lower entry of harmful gases and acidic liquid. Hence, the durability and long life of concrete structure can be increase.

Electrical resistivity of concrete

The corrosion is an electrochemical process. The severity of corrosion was checked by ER meter. The bulk electrical resistivity was observed at 7 days and 28 days for triple blend concrete mix of 80C1R10F10 was observed 16.40 kΩ-cm and 23.10 kΩ-cm for 70C1R10F20 triple blend concrete mix was observed the increased in ER 21.00 kΩ-cm and 26.50 kΩ-cm, for 60C1R10F30 triple blend concrete mix was observed increased in ER 22.50 kΩ-cm and 27.70 kΩ-cm with respect to control concrete as 10.20 kΩ-cm and 13.40 kΩ-cm. Again the ER increase with respect to curing period at 56 days and 90 days for 80C1R10F10 ER was observed to be 28.70 kΩ-cm and 34.30 kΩ-cm, for 70C1R10F20 triple blend concrete mix was observed to be in ER 31.60 kΩ-cm and 38.20 kΩ-

cm, for 60C1R10F30 triple blend concrete mix was observed the increased in ER 33.20 kΩ-cm and 39.80 kΩ-cm with respect to reference concrete. Whereas, increased in the ER at (7, 28, 56, and 90 days) triple blend concrete for 10% type-2 RHA and 10% FA as cement replacement the ER were achieved 14.30 kΩ-cm, 18.50 kΩ-cm, 22.80 kΩ-cm and 27.50 kΩ-cm, for 20% FA as cement replacement the ER was achieved 16.80 kΩ-cm, 21.80 kΩ-cm, 25.30 kΩ-cm and 31.00 kΩ-cm, than control concrete mix. And for 30% FA as cement replacement the ER were achieved 19.60 kΩ-cm, 24.60 kΩ-cm, 28.70 kΩ-cm and 33.30 kΩ-cm, than reference concrete mix. For the combination of 10% type-3 RHA and 10% FA triple blend concrete ER were achieved 12.70 kΩ-cm, 15.30 kΩ-cm, 18.60 kΩ-cm and 21.0 kΩ-cm, for 20% FA as cement replacement the ER was achieved 14.30 kΩ-cm, 16.90 kΩ-cm, 19.80 kΩ-cm and 22.40 kΩ-cm, than control concrete mix. And for 30% FA as cement replacement the ER were achieved 15.40 kΩ-cm, 18.80 kΩ-cm, 22.50 kΩ-cm and 25.30 kΩ-cm, than control concrete mix. The higher ER was achieved for low water-cement ratio as 0.30 and also the ER increased with increased in cement replacement by FA and RHA content and curing days, and hence the severity of concrete was a low rate of corrosion. The increase in ER was due to the dense particle packing in the concrete matrix. The finer particle of FA and RHA filled the voids. The details of the test result are shown in Figure 2. Higher electrical resistivity shows the better resistance of concrete against corrosion. Also from electrical resistivity test chloride permeability can be predicted. The relation between ER and corrosion rate the guideline are given by ACI Committee 222R-01 [31]. The severity of corrosion for concrete noticed from the experimental test results and with reference to ACI Committee 222R-01, it was observed that the ER of the triple blend concrete lies between 20 to 200 kΩ-cm for all mixes. Whereas the control concrete corrosion severity lies between 10 to 20 kΩ-cm it indicates moderate rate of corrosion. It was also noticed that the ER decreased with increased in water cement ratio. It can be conclude that the addition of FA and RHA along with OPC triple blend concrete achieved high ER and hence less chance of corrosion. The higher ER reflects the lower corrosion rate and hence increased the durability and long life of triple blend concrete.

Water absorption by concrete

The incorporation of pozzolanic material in concrete has two benefits like increase the strength and resistance to water

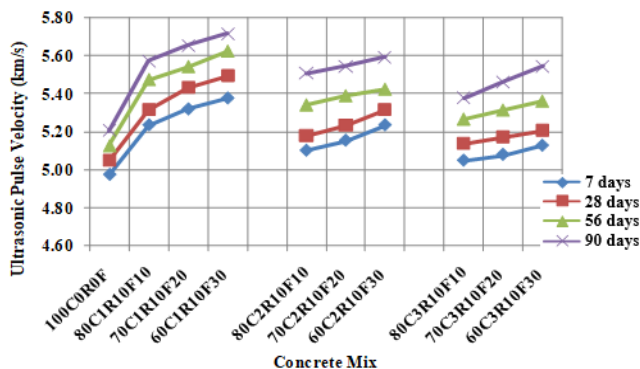


Figure 1. UPV values for different concrete mixes

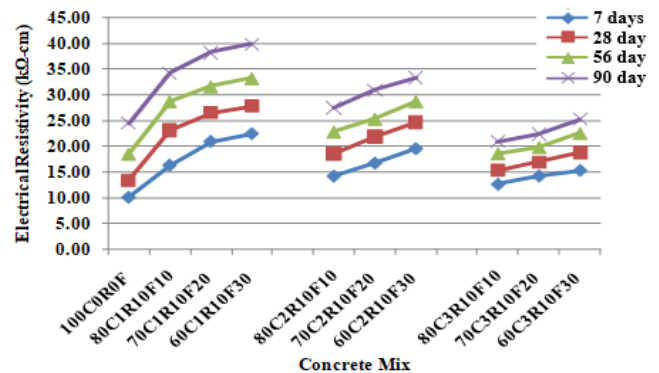


Figure 2. Variation in ER for different concrete mixes

penetration. These improvements are mostly due to the reduction of penetration. In Figure 3 it is seen that the percentage of water absorption at 28 days, 56 days and 90 days cured specimens. The percentage of water absorption for triple blend concrete mix of 80C1R10F10 was observed to be 4.61%, 4.20% and 3.00% whereas the control concrete 5.45%, 5.12% and 4.79%, for 70C1R10F20 triple blend concrete mix the percentage of water absorption was observed to be 4.23%, 4.11%, and 2.94%, for 60C1R10F30 triple blend concrete mix the percentage of water absorption was observed to be 4.0%, 3.84%, and 2.83%. And the percentage of water absorption for 10% type-2 RHA and 10% FA as partial cement replacement was found by 4.66%, 4.23%, and 3.19%, for 20% FA as cement replacement the percentage of water absorption was observed to be 4.52%, 4.12%, and 3.03%. For 30% FA replacement the percentage of water absorption observed 4.11%, 4.09% and 2.19% than control concrete mix. For the combination of 10% type-3 RHA and 10%FA, the percentage of water absorption was observed to be 4.73%, 4.36%, and 3.38%, for 20% FA as replacement the percentage of water absorption was observed to be 4.66%, 4.17%, and 3.12%. And for 30% FA as a replacement, the percentage of water absorption was observed to be 4.60%, 4.13% and 2.94% which was less than control concrete mix. It was noticed that the porosity reduced with increased in SCM content in concrete this was due to the fine particles of FA and RHA filled the voids between cement particles and block the water diffusion path. The SEM image shows the dense particle packing in the concrete matrix. Another reason is the fully utilization of calcium hydroxide after 40% SCM addition resulting dense CSH gel formed and reduction in voids [32]. The reduction in water absorption increased the durability and life of concrete structure.

Accelerated carbonation

The corrosion and deterioration of concrete reinforcement is the most serious durability problem. In the concrete carbonation process [33] initially diffusion of CO₂ into the pores. Then the first the soluble alkali metal hydroxide reaction takes place. It reducing the pH and allowing more Ca(OH)₂ into the solution. The reaction between Ca(OH)₂ and CO₂ takes place formed Ca(HCO₃)₂ and then CaCO₃. The final product calcium carbonate breaks the passive layer on reinforcement and corrosion will start. The carbonation depth was observed at 28 days of curing as shown in Figure 4. The triple blend concrete mix of 80C1R10F10 was observed

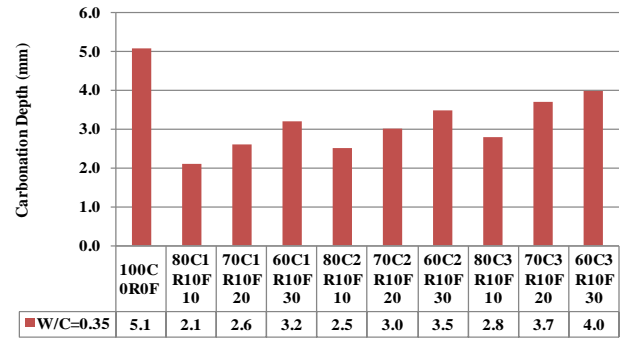


Figure 4. Depth of carbonation for different concrete mixes

58.8% decreased, for 70C1R10F20 triple blend concrete mix was observed the decreased in carbonation depth 49%, for 60C1R10F30 triple blend concrete mix was observed decreased in carbonation depth 37.3% concerning control concrete. Whereas, decreased in carbonation depth at 28 days triple blend concrete for 10% type-2 RHA and 10% FA as cement replacement the decreased in carbonation depth was 51%, for 20% FA as cement replacement the decreased in carbonation depth was 41.2% than control concrete mix. And for 30% FA as cement replacement, the decreased in carbonation depth was 31.4%, then control concrete mix. And for the combination of 10% type-3 RHA and 10% FA the decreased in carbonation depth was 28 days triple blend concrete was observed 45.1%, for 20% FA as cement replacement the decreased in carbonation depth was 27.5%, then control concrete mix. And for 30% FA as replacement of cement, the decreased in carbonation depth was 21.6%, then control concrete mix. The test results were shows the depth of carbonation decreased in FA and RHA triple blend concrete than control concrete. This was due to the dense particle packing in the concrete matrix resulting in reduced the diffusion of carbon dioxide. The fine particle of FA and RHA filled the maximum micro pores and cracks resulting in triple blend concrete more durable.

Formation factor for triple blend concrete

The transportation of ions through pore solution referred as diffusion it is equivalent to the flow of current under a potential difference called electrical resistance. Hence it may easy to determine or study the electrical resistivity of concrete. It is useful method for examine the transport processes called performance and durability of concrete. The similarity between hardened concrete and rock both are referred as porous solid. The formation factor (*F*) is the general method to determine the conductivity of rock. The main reason to determine formation factor for the triple blend concrete is that, the different binder system formed in concrete and each binder system in triple blend concrete has its own pore solution properties. Hence by normalizing the concrete resistivity to the pore solution resistivity the formation factor may be determined. The ratio of the conductivity of the saturating liquid (ρ_p) to the bulk conductivity of the saturated rock (ρ) called formation factor. In case of concrete formation factor (*F*) is can be determined by given Equation (1) [34, 35],

$$F = \frac{\rho_{sat}}{\rho_{p,sat}} \tag{1}$$

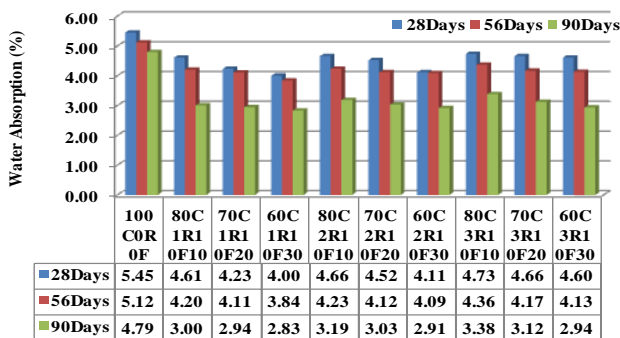


Figure 3. Percentage of water absorption for different concrete mixes

where, (ρ_{sat}) denotes saturate resistivity of concrete and ($\rho_{p,sat}$) denotes saturate resistivity of pore solution. The calculated formation factor values can be correlated with durability properties of concrete. The formation factor is a numerical quantification of microstructure. Figure 5 illustrates the relation of formation factor with durability properties of concrete. It shows that if the formation factor increased the porosity and water absorption decreased, subsequently formation factor increase the UPV and ER enhanced. This was due to the effect of resistivity of pore solution. Hence it can be conclude that the durability of triple blend concrete depends on microstructure properties such as resistivity of pore solution.

Microstructure investigation

The large number of hollow shell pores was observed in Figures 6 (a) and 6(b) [36] and large unhydrate cement content present in control concrete, whereas less in the triple blend concrete. The interfacial transition zone (ITZ) of the triple blend concrete improved [37]. The improvement was shown due to the addition of fine FA and RHA resulting in more homogeneous, stronger and thinner ITZ, with lesser micro cracks and voids.

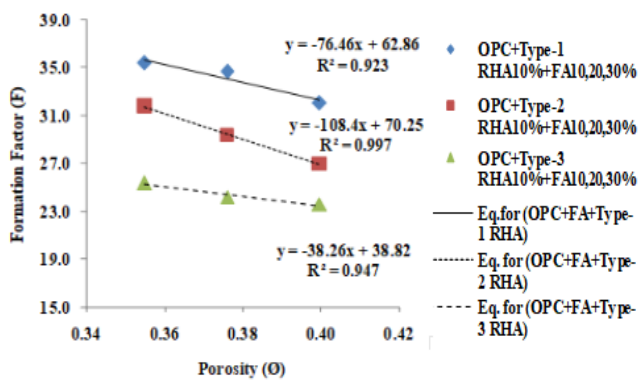


Figure 5. Formation factor versus porosity of concrete mixes

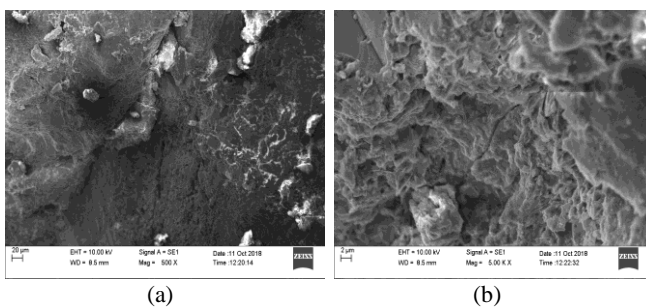


Figure 6. SEM image of (a) Control concrete, (b) Triple Blend Concrete

CONCLUSIONS

Following conclusions have been made from the test results, The triple blend concrete mix of 40% replacement of cement by FA and type-1RHA improved the durability of concrete at all ages than control concrete.

1. The triple blends concrete has well resistant to corrosion in terms of water absorption, electrical resistivity and carbonation.
2. The durability of triple blend concrete enhanced with increase in formation factor. Hence formation factor can be a good indicator to study the durability properties of triple blend concrete.
3. The ultrasonic pulse velocity, electrical resistivity, and SEM images indicate that the triple blend concrete improved the dense particle packing in the concrete matrix.
4. In the triple blend concrete, the use of FA and RHA up to 40% as partial cement replacement can reduce the consumption of cement and environmental issues.
5. The suggested type of triple blend concrete is strongly recommended for making the durable and sustainable concrete.

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Persian Abstract

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چکیده

ارزیابی اثرات محیطی روی بتن یکی از مهم‌ترین جنبه‌های دوام و پایداری آن است. استفاده از مواد افزودنی به سیمانی (SCM) در بتن می‌تواند مقاومت و دوام بتن را افزایش دهد. این امر می‌تواند پایداری بتن را بهبود داده و مشکلات محیط زیستی را کاهش دهد. در این مقاله پژوهشی مطالعات آزمایشگاهی بر روی عملکرد بتن مخلوط سه‌گانه ساخته شده از مخلوط خاکستر (FA) و خاکستر برنج (RHA) به همراه سیمان پرتلند معمولی (OPC) ارائه شده است. در پژوهش حاضر، از ترکیب بتن به عنوان ۲۰٪، ۳۰٪ و ۴۰٪ جایگزین سیمان توسط FA و RHA استفاده شده است. خواص مقاومت و دوام بتن مانند سرعت پالس اولتراسونیک (UPV)، مقاومت الکتریکی (ER)، جذب آب و کربناسیون عمق بتن مخلوط سه‌گانه مشخص شد و برای فاکتور شکل‌گیری عملکرد ریزساختار و با استفاده از میکروسکوپ الکترونی روبشی (SEM) انجام شده است. بهبود مقاومت و دوام بتن تا ۴۰ درصد جایگزین سیمان صورت گرفته است. مقاومت و دوام بتن با افزایش ضریب شکل‌گیری بهبود می‌یابد. تصاویر SEM بهبود در دانه‌بندی ذرات بتن را ثابت کرده است.
