Innovative Infrastructure Solutions (2022) 7:115
https://doi.org/10.1007/s41062-021-00715-6

PRACTICE-ORIENTED PAPER

Evaluation of pavement quality concrete prepared with locally available supplementary cementitious materials

Rahul Kumar[1] · Ranja Bandyopadhyaya[1] · Hillol Chakravarty[1]

Received: 28 August 2021 / Accepted: 19 November 2021 / Published online: 29 November 2021

Abstract
The present research aims to assess use of supplementary cementitious materials namely rice husk ash (RHA), cow dung ash (CDA) as partial replacement of cement for low volume concrete road construction. RHA and CDA was prepared by controlled burning using ferro cement furnace. Strength, durability and workability properties for normal and blended concrete were tested to obtain optimum cement replacement proportion with CDA, RHA and CDA–RHA blend. Strength tests included compressive strength, flexural strength, strength activity index; durability tests included ultrasonic pulse velocity test (UPV) and rapid chloride permeability test (RCPT). The optimum levels of CDA, RHA and CDA–RHA mix blends were obtained by comparing mean compressive and tensile strengths for normal concrete and different levels of replacement of cement with CDA, RHA and CDA–RHA mix blended concrete using ANOVA and t-tests. It could be observed that optimum compressive and flexural strengths could be obtained at 10% replacement level with CDA, 15% with RHA and 10% with CDA–RHA blend in 3:7 ratio. UPV and RCPT results show that blended concrete was durable compared to normal concrete. Blended concrete 15% RHA and 10% CDA–RHA blend was found reduce pavement cost by 4–9% for rural roads. The novelty of the research lies in the analysis provided on blending of such locally available SCMs and the comprehensive cost analysis depicting the usage of such blended concrete for usage in low volume road construction.

Keywords Concrete pavement · Strength test · Durability test · RHA · CDA · Economic analysis

Introduction

Conventionally pavements are categorised as flexible and rigid. Flexible pavements are used widely because of various advantages associated with these pavements. Newer and innovative materials and techniques have facilitated such wide usage of flexible pavements [1, 2]. However, these pavements face various durability issues and rigid pavements performs better with respect to durability. Cement concrete roads or rigid pavements though more durable are expensive as its major component cement. Moreover, production of cement is energy intensive as compared to flexible pavements. A wide range of research has been conducted focusing on making cement concrete more economical by probing for possible usage of cementitious material which can be used as replacement or partial replacement of cement along with locally available Supplementary Cementitious Materials (SCMs) such as Rice Husk Ash (RHA), Sugarcane Bagasse Ash (SBA), Cow-Dung Ash (CDA) etc. [3]. Use of SCMs in cement concrete also provides a means of doing away with problems related to their proper disposal.

Researchers also aimed to study various properties of concrete where bio-wastes have been used as partial substitute of cement in concrete. RHA is the most popular SCM used for various concrete works and suitability of RHA as partial replacement of cement has been extensively studied by researchers [4–8]. Researchers observed that concrete achieves optimum compressive strength when cement was replaced by RHA at 10 to 20% levels by weight [9–15]. Optimum flexural strength was achieved by concrete when cement was replaced by 7.5% RHA by weight [8]. Optimum split tensile strength was achieved by concrete when cement was replaced by 15% RHA by weight, but the resultant

✉ Ranja Bandyopadhyaya
ranja@nitp.ac.in

Rahul Kumar
sunnykkumar06@gmail.com

Hillol Chakravarty
hillol140870@nitp.ac.in

[1] Department of Civil Engineering, National Institute of Technology Patna, Patna 800005, Bihar, India

concrete was not found suitable for fast-track construction [6, 12, 13]. Optimum modulus of elasticity was observed to be achieved by concrete when cement was replaced by 20% RHA by weight [12]. Optimum dynamic elastic modulus of concrete, which was measured by Ultrasonic Pulse Velocity (UPV) test, was also observed to be achieved at 20% replacement of cement with RHA by weight and at this replacement, concrete was found unsuitable for fast tract construction [6, 7]. Corrosion of reinforcing steel in concrete is common phenomena which occurs by penetration of chloride in concrete. Researchers observed chloride ion penetration to be acceptable for concrete where up to 30% weight of cement was replaced by RHA [6, 8, 12, 13, 15, 16]. Concrete, with RHA used as partial replacement of cement, is popularly used in buildings but not for road construction. Investigation on possible use of RHA in concrete pavement is limited [17, 18].

Researchers also aimed to study various properties of concrete when CDA was used as partial replacement of cement for suitability in concrete works, mortar and concrete blocks. Researchers observed that concrete achieves optimum compressive strength when cement was replaced by CDA at 5 to 10% levels by weight [17–23]. Optimum flexural strength and split tensile strength was observed to be achieved by concrete when cement was replaced with 10% CDA by weight [23, 24]. Chloride penetration test showed that concrete performed satisfactorily when cement was replaced by 10% CDA by weight. Systematic investigation on possible use of CDA as partial replacement for cement in concrete pavement is however very limited.

It could be observed that systematic investigation of strength properties for concrete where cement was partially replaced with CDA and RHA has been done [5–9, 11–15, 17–23]. However, investigation on durability properties of such concrete is limited [6, 7, 9–11, 17–23]. Research on ternary blending of CDA and RHA with cement for possible use in concrete pavement were not observed in literature. Moreover, literature on replacement of locally available SCMs such as CDA and RHA for pavement construction along with comprehensive cost analysis are also not found in the literature. Thus, the primary objectives of this research may be stated as:

(1) To investigate the strength, durability and workability properties of concrete when cement is partially replaced with CDA, RHA and their combination and determine the optimal proportion of such replacement. The strength is measured by conducting compressive strength tests, flexural strength tests and strength activity index. The durability was measured by ultrasonic pulse velocity test (UPV) and rapid chloride permeability test (RCPT). Workability was measured using slump test, setting time and consistency tests.
(2) Design the required pavement thickness for low volume roads for varied traffic conditions using normal as well as blended concrete with optimal dosage of RHA, CDA and their combination as per IRC SP 62–2014.
(3) Determine cost of construction for normal and blended concrete thereby providing comparative cost analysis. Thus, assessments of whether the blended concrete provides a cost-effective solution for such pavement construction is performed.

Split tensile strength test was not included in the analysis. This was because the concrete mixtures were used for pavement construction and compressive and flexural strength test is the requisite test for that purpose. Water permeability could have been used as the parameter for determining durability. However, RCPT, UPV and density were chosen as parameters as they sufficiently provide the durability parameters advocated for pavement construction. The CDA and RHA required controlled burning of cow dung and rice husk for having pozzolanic properties and ferro cement furnace was used in the study for that purpose. X ray florescence (XRF) test was required for determining the chemical composition for CDA and RHA for which the samples were sent for third party testing. The next section gives a brief overview of the methodologies adopted for the present work. Section 3 provides the results and analysis for the experiments conducted for this work. Section 4 presents calculation of pavement slab thickness for low volume roads, using proposed modified concrete (where CDA, RHA and RHA-CHA blend has been used as partial replacement of cement) as per IRC 62 guidelines. Section 5 presents evaluation of cost effectiveness for modified concrete for low volume roads. Section 6 presents the discussion of the results and cost analysis. Section 7 presents the conclusions that could be drawn from the work.

Methodology

This work aims to study the strength, durability and workability properties of concrete when cement is partially replaced with CDA, RHA and mixture of both. The detailed methodology of the work is shown in Fig. 1.

Initially, properties of individual constituent materials namely coarse aggregates (10–20 mm), sand, cement, CDA and RHA were tested as provided in Table 1. The coarse aggregates were obtained from Gaya, Bihar, India and sand from Sone river bed, Bihar, India. OPC 43 grade cement was used for the study. CDA was prepared by controlled burning of dried cow dung at 400–500˚C. The RHA was prepared by controlled burning of rice husk at 600–700˚C. The controlled burning was done using ferro cement furnace. Both

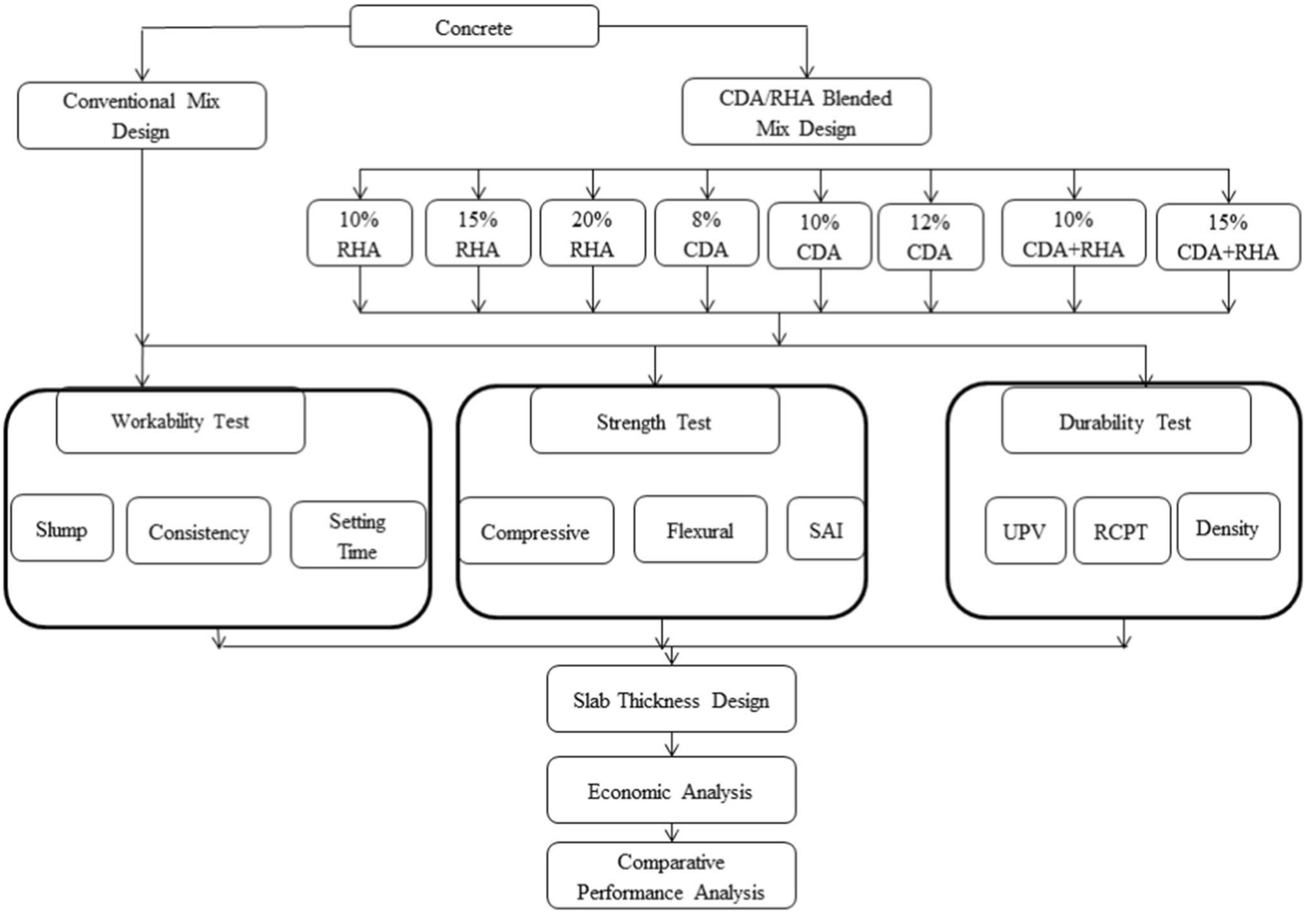

Fig. 1 Methodology for the research work

Table 1 Results of tests on aggregates

Tests performed	Results obtained	Acceptable limit	Code
Specific gravity	2.74		ASTM C127-15
Water absorption	0.6%	2% (Max)	
Aggregate crushing value	21.2%	30% (Max)	BS EN 1097–20
Aggregate impact value	7.6%	30% (Max)	ASTM C131/C131M-20
Los angeles abrasion test	22.64%	30% (Max)	
Flakiness and elongation Index	25.88%	35%(Max)	ASTM D4791-19

CDA and RHA ash were then sieved through 300 micron sieve in order to obtain particles with increased surface area.

In order to determine the optimum proportion of CDA replacement with OPC, strength, durability and workability tests for concrete with partial replacements of OPC with 8%, 10% and12% CDA was conducted. To determine the optimum proportion of RHA replacement with OPC, strength, durability and workability tests for concrete with partial replacements of OPC with 10%, 15% and 20% RHA was conducted. To determine the optimum proportion of ternary blend of CDA and RHA with OPC, strength, durability and workability tests for concrete with partial replacements of OPC with 7% RHA and 3% CDA and with 10% RHA and 5% CDA were conducted.

Results and analysis

Strength and durability tests were performed on aggregates and modified concrete mixes. Physical and chemical composition testing of binding materials namely cement, CDA and RHA was also conducted. This section details the experimental outcomes for the tests performed. The next section details the experimental results of individual constituent materials namely aggregates, cement and SCMs namely RHA and CDA. Section 3.2 details the concrete mix design for the work. Section 3.3 details the strength, durability and workability tests performed on concrete mixes.

Experimental results of component materials

The following sub Sect. 3.1.1 details the test on aggregates. Section 3.1.2 discusses the tests of cement. Sub Sect. 3.1.3 discusses the results on tests performed on CDA and RHA.

Tests on aggregates

The results for tests performed on aggregates as per relevant code of practice and is presented in Table 1. The results indicate that the aggregates satisfied quality requirement for concrete works.

Figure 2 shows the aggregate gradation used for the design of concrete.

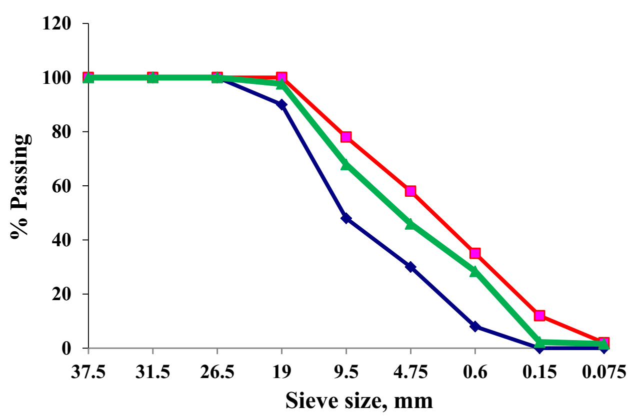

Fig. 2 shows the aggregate gradation used for the design of concrete

Tests on cement

The various physical tests were performed on cement and blended cement is represented in Table 2.

Tests on CDA & RHA

The CDA and RHA were tested in the laboratory for chemical compositions as shown in Table 3. As per ASTM C618-05 [25],the combined percentage composition of silica (SiO_2), aluminum oxide (Al_2O_3) and Ferric oxide (Fe_2O_3) should be more than 70 percent for cementitious material for class F pozzolanic material.

Table 3 shows that the combined percentage of silica (SiO_2), aluminum oxide (Al_2O_3) and Ferric oxide (Fe_2O_3) was greater for both RHA and CDA and could be classified as class F pozzolanic material. The silica and alumina available in the ash reacted with the calcium present in the cement in the form of calcium hydroxide to form the calcium silicates and calcium aluminate which were very important parameters for cementing behaviour. RHA had 95.6% oxides whereas CDA had 73.66% oxides for pozzolanic action. XRF (X-ray fluorescence) analysis was done on CDA and RHA sample to find their chemical composition.

Concrete mix design

Concrete mix design was done as per guidelines of IS 10262–2019 [26], IS 456–2000 [27]and IRC 44–2017 [28] as provided in Table 4. The cube moulds of sizes

Table 3 Chemical composition of CDA & RHA as tested [26, 27]

S. No	Test	Unit	CDA	RHA
1	Silica (SiO_2)	%	66.24	93.66
2	Phosphate (PO_4)	%	0.01	1.16
3	Titania (TiO_2)	%	0.32	0.02
4	Magnesia (MgO)	%	0.23	1.05
5	Ferric Oxide (Fe_2O_3)	%	2.43	1.02
6	Aluminum oxide (Al_2O_3)	%	4.99	0.92
7	Sulphur Trioxide (SO_3)	%	1.39	< 0.1
8	Manganese Oxide (MnO)	%	0.23	–
9	Calcium Oxide (Cao)	%	11.78	–

Table 2 Physical characteristics of cement, CDA and RHA

Parameter	Cement	CDA	RHA
Physical state	Solid–Non Hazardous	Solid–Non Hazardous	Solid–Non Hazardous
Appearance	Very fine powder	Fine powder	Fine powder
Colour	Grey	Light grey	Dark grey
Odour	Odourless	Odourless	Odourless
Specific Gravity	3.16	2.51	2.11

Table 4 Concrete mix proportions for different mixes

Mix	Cement	CDA/RHA or RHA + CDA				Coarse Aggregate		Fine Aggregate	Water	w/c ratio	Super plasticizer
						20 mm	10 mm				
	Kg/m^3	% CDA	Kg/m^3	% RHA	Kg/m^3	Kg/m^3		Kg/m^3	Kg/m^3		Kg/m^3
0%	417	–	–	–	–	640	640	621	154	0.37	2.5
8% CDA	383.64	8	33.36	–	–	640	640	621	154	0.37	2.5
10% CDA	375.30	10	41.70	–	–	640	640	621	154	0.37	2.5
12% CDA	366.96	12	50.04	–	–	640	640	621	154	0.37	2.5
10% RHA	375.30	–	–	10	41.70	640	640	621	154	0.37	2.5
15% RHA	354.45	–	–	15	62.55	640	640	621	154	0.37	2.5
20% RHA	333.60	–	–	20	83.40	640	640	621	154	0.37	2.5
10% MIX	375.30	3	12.51	7	29.19	640	640	621	154	0.37	2.5
15% MIX	354.45	5	41.70	10	20.85	640	640	621	154	0.37	2.5

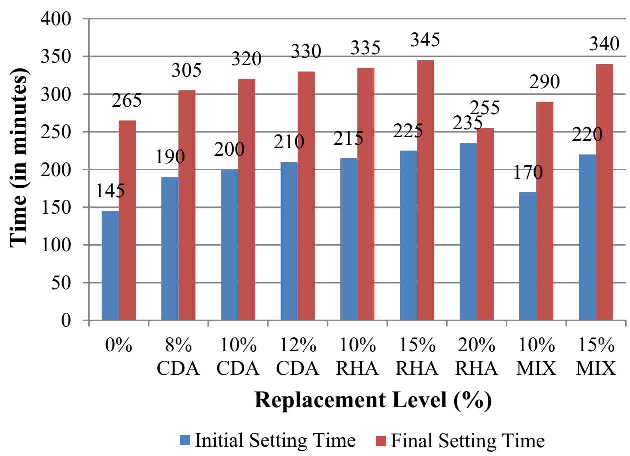

Fig. 3 Setting time of Blended Cement Paste

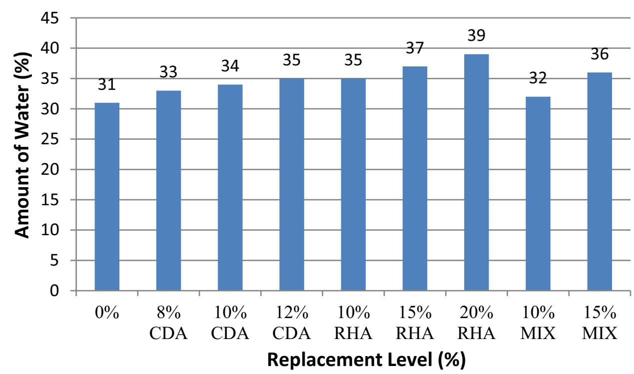

Fig. 4 Consistency values for Blended Cement Paste

(150 mm × 150 mm × 150 mm) and beam moulds of sizes (100 mm × 100 mm × 500 mm) were casted and cured for 7 and 28 days and later strength and durability tests were performed on these samples.

Tests on Concrete

Workability, durability and strength tests were performed on concrete and modified concrete mixes and is presented in this section.

Workability tests

This subsection details the workability tests, setting time and consistency.

Setting time and consistency The initial and final setting time and consistency tests were performed as per ASTM C191-19 [29] and ASTM C187-11 [30]. The obtained results are provided under in Figs. 3 and 4.

It may be observed that consistency increases as the replacement of cement by CDA, RHA and mix of CDA and RHA increases, compared to natural concrete. This is because of increased water requirement of achieving the desired consistency. Similar results are also observed for both initial and setting time values. Just like other hydraulic cement, the reactivity of CDA and RHA cement depends very much upon the specific surface area or particle size. SCMs such as RHA and CDA have reduced hydration rate resulting in delayed onset of setting.

Slump test The results of the slump test carried out on concrete with varying percentage of CDA, RHA and CDA–RHA mix as cement replacement are presented in Fig. 5.

All the slump values were the true slump type and suitable for concrete works. In this study, it is found that the slump decreases with increase in the amount of CDA and RHA. This can be attributed to the fact that CDA and RHA absorb more water than Ordinary Portland cement.

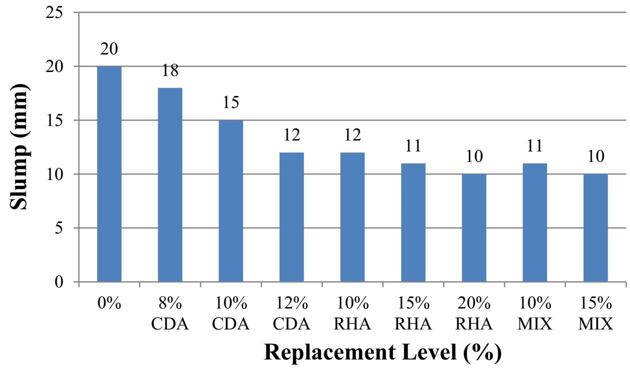

Fig. 5 Slump values of different blended specimens

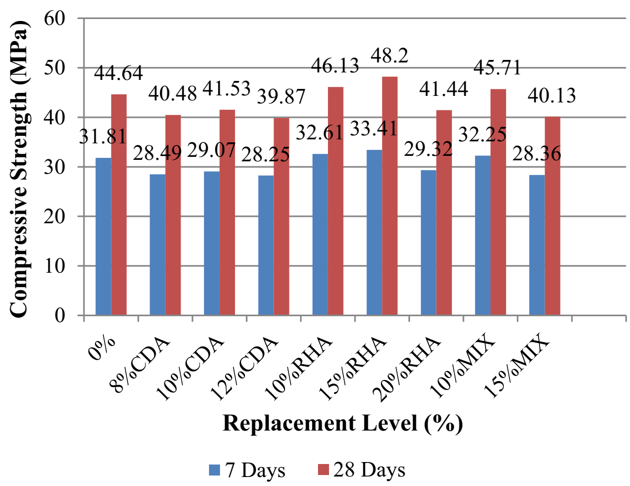

Fig. 6 Compressive Strength of blended concrete at various replacement levels

Strength test

Compressive strength, flexural strength and strength activity index (SAI) were determined to evaluate strength of concrete and is discussed in this subsection.

Compressive strength test The compressive strength test was conducted as per IS 516–2018 [31] and results have been provided in Fig. 6 for CDA, RHA and mixture blended concrete after 7 and 28 days of curing period. 54 numbers of cubes were casted corresponding to 3 cubes per tests (for both 7 days and 28 days).

In order to find whether there is a significant difference in compressive strength of concrete with addition of different SCMs namely, CDA, RHA and CDA–RHA blend at different proportions, three one-way ANOVA tests were performed. The hypothesis and results of the tests are detailed in Table 5.

It may be observed from Table 5 that null hypothesis was rejected in all cases confirming that compressive strength of concrete varied with proportion of replacement of cement with SCMs. Pairwise t-test with normal concrete and blended concrete at different percentage of blending of CDA, RHA and CDA–RHA mix were performed to check whether the strength is same as of normal concrete or is significantly higher or lower for 28 day curing. It could be observed that for RHA blending of 10 and 15% the compressive strength increased significantly ($p \leq 0.01$), whereas for RHA replacement of 20% the compressive strength is significantly lower than that of normal concrete. Moreover, for RHA blending of 15% the compressive strength was observed to be significantly more than for RHA blending

Table 5 Comparing compressive strengths with ANOVA

Material	Hypothesis	7 Day	28 Day
NC & CDA Blend	H0 There is no significant difference between the mean compressive strength for normal concrete and different levels of CDA blending concrete H1 At least one mean value of compressive strength is significantly different	MS 24.2/3 (BG) MS 11.35/8 (WG) F 5.7 *P* 0.02 Reject H0	MS 40.5/3 (BG) MS 4.03/8 (WG) F 26.76 *P* 0.00 Reject H0
NC & RHA Blend	H0 There is no significant difference between the mean compressive strength for normal concrete and different levels of RHA blending concrete H1 At least one mean value of compressive strength is significantly different	MS 28.2/3 (BG) MS 8.5/8 (WG) F 8.85 *P* 0.006 Reject H0	MS 72.9/3 (BG) MS 2.31/8 (WG) F 84.17 *P* 0.00 Reject H0
NC & CDA–RHA mix Blend	H0 There is no significant difference between the mean compressive strength for normal concrete and different levels of CDA–RHA mix blending concrete H1 At least one mean value of compressive strength is significantly different	MS 27.3/3 (BG) MS 4.1/8 (WG) F 20.1 *P* 0.002 Reject H0	MS 52.6/3 (BG) MS 1.96/8 (WG) F 80.44 *P* 0.00 Reject H0

MS Mean Square = (Sum of Square/Degree of Freedom); *BG* Between Groups; *WG* Within Groups; *F* F value; *P* Prob Value; Hypothesis H0 is Rejected when $P < 0.01$ (99% Confidence) of 10%. However for CDA blended concrete the strength was observed to be significantly lower than that of normal concrete for all replacement levels, but 10% CDA blending provided maximum compressive strength among the other blending proportions. For 10% CDA–RHA mix blended concrete compressive strength was observed to be significantly higher than that of normal concrete ($p \le 0.05$). For 15% CDA–RHA mix blended concrete compressive strength was observed to be significantly lower than that of normal concrete.

Flexural strength test The flexural strength test was conducted as per ASTM C293/C293M-16 [32]and results have been provided in Fig. 7 for CDA, RHA and mixture blended concrete after 7 and 28 days of curing period. 54 numbers of beams were casted corresponding to 3 beams per tests (for both 7 days and 28 days).

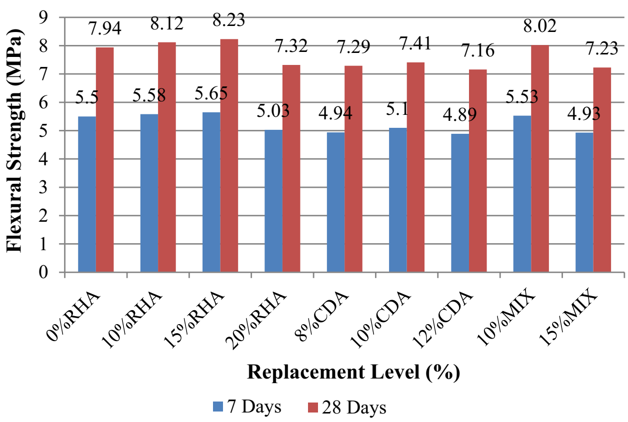

Fig. 7 Flexural Strength of blended concrete at various replacement levels

In order to find whether there is a significant difference in flexural strength of concrete with addition of different SCMs namely, CDA, RHA and CDA–RHA blend at different proportions, three one-way ANOVA tests were performed. The hypothesis and results of the tests are detailed in Table 6.

It may be observed from Table 6 that null hypothesis was rejected in all cases confirming that flexural strength of concrete varied with proportion of replacement of cement with SCMs except for CDA–RHA mix blends when checked after 28 day curing. Pairwise t-test with normal concrete and blended concrete at different percentage of blending of CDA, RHA and CDA–RHA mix were performed to check whether the strength is same as of normal concrete or is significantly higher or lower for 28 day curing. It could be observed that for RHA blending of 10 and 15% the flexural strength increased significantly ($p \le 0.01$), whereas for RHA replacement of 20% the flexural strength is significantly lower than that of normal concrete. Moreover, for RHA blending of 15% the flexural strength was observed to be significantly more than for RHA blending of 10%. It could be observed for 8% CDA blended concrete that the flexural strength was significantly lower than that of normal concrete ($p \le 0.01$), but for 10% CDA blended concrete it could be observed that flexural strength was not significantly different from normal concrete ($p = 0.02$). For 10% CDA–RHA mix blended concrete flexural strength was observed not to be significantly different that of normal concrete ($p = 0.86$). For 15% CDA–RHA mix blended concrete flexural strength was observed to be significantly lower than that of normal concrete ($p = 0.02$).

Thus from the perspective of compressive and flexural strengths 15% RHA blending, 10% CDA blending and 10% CDA–RHA mix blending may be taken to be optimum levels of replacements.

Table 6 Comparing flexural strengths with ANOVA

Material	Hypothesis	7 Day	28 Day
NC & CDA Blend	H0 There is no significant difference between the mean flexural strength for normal concrete and different levels of CDA blending concrete H1 At least one mean value of flexural strength is significantly different	MS 0.69/3 (BG) MS 0.26/8 (WG) F 7.05 P 0.01 Reject H0	MS 1.05/3 (BG) MS 0.13/8 (WG) F 22.41 P 0.00 Reject H0
NC & RHA Blend	H0 There is no significant difference between the mean flexural strength for normal concrete and different levels of RHA blending concrete H1 At least one mean value of flexural strength is significantly different	MS 0.70/3 (BG) MS 0.19/8 (WG) F 9.69 P 0.005 Reject H0	MS 1.47/3 (BG) MS 0.36/8 (WG) F 10.84 P 0.003 Reject H0
NC & CDA–RHA mix Blend	H0 There is no significant difference between the mean flexural strength for normal concrete and different levels of CDA–RHA mix blending concrete H1 At least one mean value of flexural strength is significantly different	MS 0.69/2 (BG) MS 0.21/6 (WG) F 9.77 P 0.01 Reject H0	MS 1.11/2 (BG) MS 1.06/6 (WG) F 3.11 P 0.1 Accept H0

MS Mean Square = (Sum of Square/Degree of Freedom); *BG* Between Groups; *WG* Within Groups; *F* F value; *P* Prob Value; Hypothesis H0 is Rejected when $P < 0.01$ (99% Confidence)

Strength activity index (SAI) Strength Activity Index (SAI) is the ratio of strength achieved by blended mix to the strength achieved by control mix (normal concrete) expressed as a percentage. The Strength Activity Index (SAI) test was conducted in accordance with ASTM C311/C311M-18 [33]. The test for strength activity index was used to find whether the pozzolana will result in an acceptable level of strength development when used with hydraulic cement in concrete.

The strength activity index of 10% CDA, 15% RHA,10% mix (7% RHA + 3% CDA) and 15% mix (10% RHA + 5% CDA) are determined to be 91.39%, 105.03%,101.38% and 89.15% respectively at 7 days of curing period while 93.03%,107.97%,102.40% and 89.90% respectively at 28 days of curing period as shown in Fig. 8. This value is greater than the 75% minimum specified by ASTM Code C618-05 [25]which indicates that the CDA and RHA may react well with ordinary Portland cement to produce concrete of acceptable strength levels. The strength activity index values for CDA is lower comparable to RHA which is due to the pozzolanic reaction of RHA with $Ca(OH)_2$ producing C–S–H and increasing the compressive strength. At longer curing period of 28 days, it is observed that strength activity index is more than at 7 days of curing period, because at the later age, the amorphous aluminous and siliceous minerals could have still actively reacted with $Ca(OH)_2$,thus improving C–S–H and hydrated calcium aluminates and hence improving interfacial bonding between sand and pastes. Thus, compressive strength is increased at later age for both replacements.

Durability

Ultrasonic Pulse Velocity (UPV), Rapid Chloride Penetration Test (RCPT) and density values were determined to estimate the durability of designed concrete. The details of the durability tests are provided in this sub section.

Ultrasonic pulse velocity (UPV) test The UPV test values were determined as per ASTM C597-16 [34] for 28 days aged concrete as depicted in Fig. 9. It is observed that after

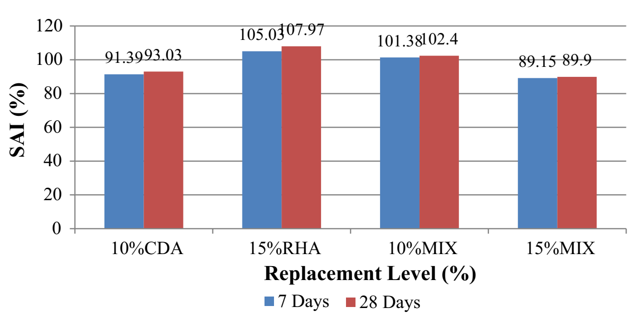

Fig. 8 Strength Activity Index (SAI) of different specimens

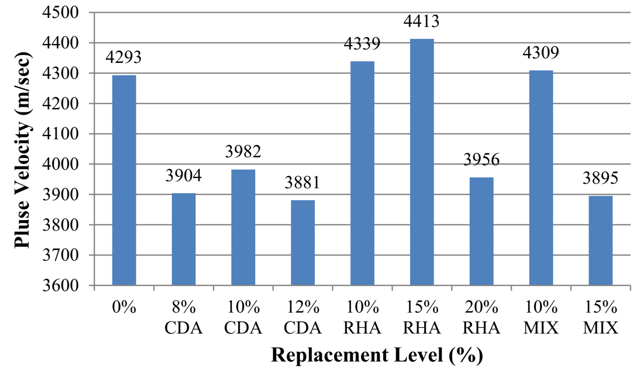

Fig. 9 Gradingof different Specimens on the basis of Pulse Velocity (For 28 days)

28 days the value of Ultrasonic Pulse Velocity for 10% RHA, 15% RHA and 10% mix increases as compared to normal concrete and for 20% RHA and 15% mix, its value decreases. The UPV value decreased for all CDA blended concrete. If more cement is used its UPV value decreases. At the end of 28 days, UPV of all specimens are more than 3660 m/sec, therefore the specimens are durable concrete.

Rapid chloride permeability test (RCPT) Figure 10 shows the rapid chloride permeability test results of CDA, RHA and mix blended concrete after 28 days curing. The test was conducted as per ASTM C1202-19 [35]. It is found that as the replacement level of cement by CDA and RHA increases, the charge passed through the specimens decreases. Replacement by CDA drastically reduces the Coulomb values as compared to RHA.

Density From the Fig. 11, it can be found that the lowest density values are for CDA, RHA and mix blended concrete specimens as compared to conventional concrete. This is due to the low specific gravity of CDA and RHA which

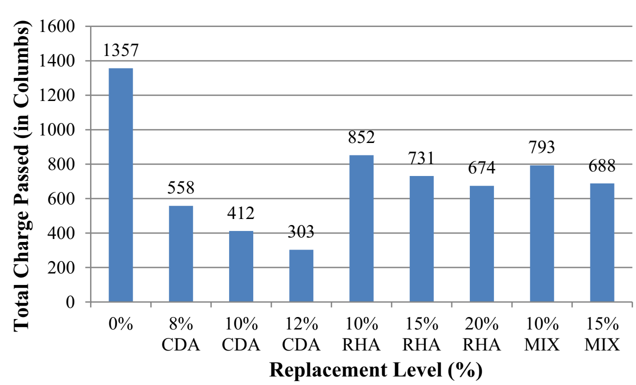

Fig. 10 Total Charge Passed (in Coulombs) for different replacement levels

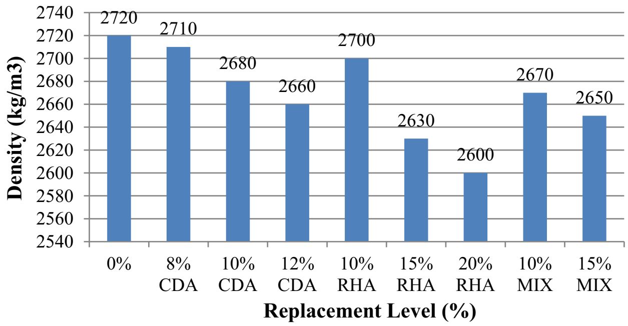

Fig. 11 Density of different blended specimens

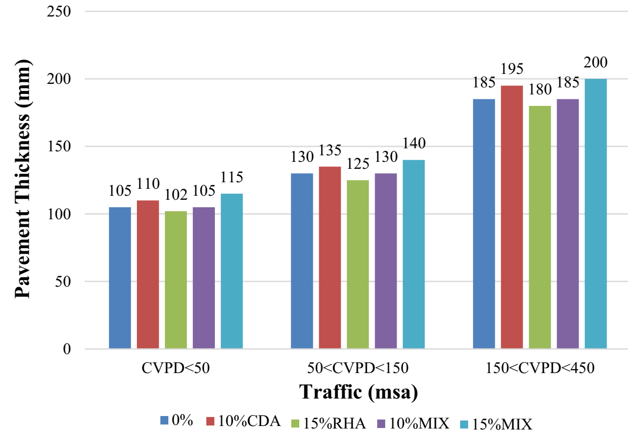

Fig. 12 Thickness of Pavement Slab for different specimens

leads to the reduction in the mass per unit volume. At 10% replacement, RHA blended concrete has lower density than CDA blended concrete, because of lower specific gravity of RHA as compared to CDA.

Pavement thickness for low volume roads

Thickness of pavement slab for low volume roads was designed for the optimum replacement levels of CDA and RHA obtained and for mix as per guidelines of IRC SP 62–2014 [36]. Thickness was designed based on three types of traffic conditions i.e. for traffic less than 50 CVPD, traffic higher than 50 and less than 150 CVPD and traffic exceeding 150 CVPD. For traffic less than 50 CVPD, only wheel load stresses for a load of 50 KN on dual wheel is considered for thickness estimation since there is a low probability of maximum wheel load and highest temperature differential between the top and the bottom of the rigid pavement, both occurring at the same time. For traffic higher than 50 and less than 150 CVPD, thickness estimation is done on the basis of total stresses resulting from wheel load of 50 KN and temperature differential both. For traffic exceeding 150 CVPD, due to fatigue problem and thickness estimation is done on the basis of fatigue fracture. Based on that, thickness of pavement slab (in mm) for different specimens are presented in Fig. 12 as given below.

Cost estimation

The estimation of cost is done for 1 km of road based on thickness of pavement slab as obtained in previous section. The rate of material is taken from Schedule of Rates published by Road Construction Department, Govt. of Bihar. Table 5 provides detailed cost estimation for the optimized combination of CDA, RHA and tertiary blend of RHA-CDA as SCM. The quantity (in kg) was estimated by determining the total volume of concrete component materials required for 1 km of road as per designed thickness calculated according to IRC SP 62–2014. The road was considered to be single lane with a width of 3.75 m.

Discussions

In this study, the potential application of locally available SCMs namely CDA, RHA and CDA–RHA blended concrete was explored for construction of low volume rural roads. Initially chemical properties of CDA and RHA were tested to assess their suitability as binding material. CDA and RHA could be classified as a class F pozzolanic material from the chemical composition tests. To assess the suitability of blended concrete for pavement construction, workability, strength and durability parameters were tested for normal concrete and blended concrete at various percentage replacement of cement with the SCMs. The optimum quantities of RHA, CDA and CDA–RHA mix for blended concrete were determined. The optimum quantities of RHA, CDA and CDA–RHA mix corresponds to proportion of replacement where the strength reaches its maximum and the concrete has acceptable durability and workability.

Consistency, setting time and slump values were used to measure workability. Consistency was found to increase with increased percentage replacement of cement by CDA, RHA and CDA–RHA mix. This may be attributed to the fine particles of RHA and CDA getting absorbed on the oppositely charged particles of cement preventing flocculation. The cement particles are thus effectively dispersed and trap large amounts of water to achieve a given consistency. Similar results were also observed for setting time. This may be attributed to the fact that SCMs such as CDA and RHA have slower pace of hydration as compared to cement thereby increasing the setting time. Specific surface area and particle sizes also contribute to setting time. The experimental result tally with the result obtained from other studies for CDA blended concrete [19, 20]. The slump was observed to decrease with increase in the amount of CDA and RHA because of more absorption of water by these SCMs as compared to OPC. The experimental result tally with the results obtained from other studies for CDA blended concrete [19]. However, literature could not provide evidence of such results for RHA blended concrete.

Compressive strength, flexural strength and Strength Activity Index (SAI) were used to measure strength of concrete. Compressive strength test results revealed that the optimum value of CDA, RHA and RHA–CDA mix replacements were 10%, 15% and 10% (3% CDA & 7% RHA) respectively. Previous studies showed that the optimum compressive strength of RHA blended concrete was achieved for RHA replacement in the range of 10% to 20% [5–7, 13, 37]. On the other hand, previous studies showed that optimum value of compressive strength of CDA blended concrete was achieved at 5% to 15% replacement of cement with CDA [17–21, 23]. Flexural strength test results reveal that the optimum value of CDA, RHA and RHA–CDA mix blended concrete were 10%, 15% and 10% respectively. Literature on flexural strength reported optimum value of flexural strength at15% to 20% cement replacement with RHA [8, 38].On the other hand past studies reported optimum cement replacement with CDA to be 10% [20]. The SAI test showed 28 day SAI to be higher than 7 day SAI. This may be attributed to late reaction of amorphous aluminous and silicious minerals with $Ca(OH)_2$ thereby forming C-S–H gel and hydrated calcium aluminates imparting greater strength with longer curing period.

UPV, RCPT and density were measured to give an estimate of durability of concrete. UPV measured at 28 day for 10% RHA, 15% RHA and 10% mix as was observed to be greater compared to normal concrete. For all CDA blended concrete, UPV values were observed to decrease. This occurrence may be attributed to the fact that control mix concrete contains more amount of cement than the blended concrete specimens and has more hydrate content at the same age. Moreover, CDA and RHA have lower specific gravity and have porous structure and their grains are not as dense as cement. As seen in Fig. 9, the experimental result for RHA blended concrete tally with the result obtained from previous studies [6, 7]. However, literature could not provide evidence for CDA blended concrete. RCPT results showed decreased chloride penetration for CDA, RHA and CDA–RHA mix concrete which indicates that addition of CDA and RHA in concrete increases its durability. Previous studies showed increased durability for RHA blended concrete [12, 15]. However, literature could not provide evidence of such experiments for CDA blended concrete. RHA blended concrete were seen to have lower density than CDA blended concrete for 10% replacement, because of lower specific gravity of RHA as compared to CDA as can be observed from Fig. 11. The experimental results tally with the result obtained from other studies for RHA blended concrete [12]. However, literature could not provide evidence of such experiments for CDA blended concrete Table 7.

Thus, the optimum values of RHA and CDA application was observed to be at 15% and 10%. Detailed cost analysis was further done to assess the cost of normal and blended concrete pavements for different traffic conditions for optimum quantities of RHA, CDA and RHA–CDA mix concretes. Table 8 provided details of the cost savings in percentage per km of road construction by using 10% CDA, 15% RHA and both 10% and 15% mix blended concrete over conventional concrete pavement. This analysis is derived from the cost calculation provided in Table 7.

It could be observed from the cost analysis that 8–9% of cost may be saved when cement was replaced by 15% RHA. Also, around 4% cost may be saved when 10% of cement was replaced with blend of CDA and RHA in 3:7 ratio. However, significant cost saving was not observed when cement was replaced by 10% CDA. Moreover, when 15% of cement was replaced with blend of CDA and RHA in 1:2 ratio the cost of construction was observed to increase marginally.

This research provides a detailed analysis of possible use of locally available SCMs such as RHA, CDA and RHA-CDA mix as partial replacement of cement concrete for construction of low volume roads. Though possible use of RHA in concrete pavement is explored, detailed analysis of CDA blended concrete and RHA–CDA mix blended is rare. As these SCMs can be made with locally available materials, the cost associated with transportation could drastically be reduced. Detailed cost analysis to analyse the economic benefits associated with usage of such SCMs is also not available in literature. Thus, this work is unique and useful. However further exploration is required with more combinations of CDA–RHA mix blended concrete to explore more economical mix blends.

Conclusions

In this work strength, durability and workability tests for normal concrete and blended concrete were performed to obtain optimum replacement of cement with RHA, CDA and mix of RHA and CDA. The optimum replacement levels for RHA and CDA blended concrete was found at 15% and 10% respectively. The optimum replacement of cement by CDA–RHA mix was found to be 10% where CDA and RHA is mixed in 3:7 ratio. The major conclusions from experimental observations are highlighted below:

Table 7 Detailed cost analysis for optimised combination of CDA, RHA and CDA-RHA

Type of Mix	Traffic	Component Materials																
		Cement (@Rs. 320/50 kg Bag)		RHA (@Rs. 1500/ Ton)		CDA (@ Rs.1000/ Ton)		Coarse Aggregates (20 mm) (Rs. 604.91/ cumec)		Coarse Aggregates (10 mm) (@Rs. 668.80/cumec)		Fine Aggregates (@Rs. 175.80/cumec)		Superplasticizer (@156.84/kg)		Water (@258.51/KL)		Total Cost
		Quantity in kg/km	Cost	Quantity in kg/km	Total Cost	Quan-tity in kg/km	Cost	Quantity in kg/km	Cost	Quantity in kg/km	Cost	Quantity in kg/km	Cost	Quantity in kg/km	Cost	Quantity in kg/km	Cost	
Normal Con-crete	CVPD < 50	164,193.8	1,050,840	–	–	–	–	252,000	89,669.01	252,000	105,336	244,518.75	23,881.33	984.38	154,390	60,637.5	15,675.4	1,439,792
	50 < CVPD < 150	203,287.5	1,301,040	–	–	–	–	312,000	111,018.8	312,000	130,416	302,737.5	29,567.36	1218.75	191,149	75,075	19,407.64	1,782,599
	CVPD > 150	289,293.8	1,851,480					444,000	157,988.3	444,000	185,592	430,818.75	42,076.63	1734.38	272,020	106,837.5	27,618.56	2,536,776
CDA (10%)	CVPD < 50	154,811.3	990,792	–	–	30,580	30,580	264,000	93,938.96	264,000	110,352	256,162.5	25,018.54	1031.25	161,741	63,525	16,421.85	1,428,845
	50 < CVPD < 150	189,995.6	1,215,972			37,530	37,530	324,000	115,288.7	324,000	135,432	314,381.25	30,704.57	1265.63	198,501	77,962.5	20,154.09	1,753,583
	CVPD > 150	274,438.1	1,756,404			54,210	54,210	468,000	166,528.2	468,000	195,624	454,106.25	44,351.04	1828.13	286,724	112,612.5	29,111.46	2,532,953
RHA (15%)	CVPD < 50	135,577.1	867,694	53,002.6	79,503.9	–	–	244,800	87,107.04	244,800	102,326.4	237,532.5	23,199.01	956.25	149,978	58,905	15,227.53	1,325,036
	50 < CVPD < 150	166,148.4	1,063,350	64,954.17	97,431.26			300,000	106,748.8	300,000	125,400	291,093.75	28,430.16	1171.88	183,798	72,187.5	18,661.19	1,623,813
	CVPD > 150	239,253.8	1,531,224	93,534.01	140,301.1			432,000	153,718.3	432,000	180,576	419,175	40,939.43	1687.5	264,668	103,950	26,872.11	2,338,298
MIX (10%)	CVPD < 50	147,774.4	945,756	25,462.03	38,193.05	8757	8757	252,000	89,669.01	252,000	105,336	244,518.75	23,881.33	984.38	154,390	60,637.5	15,675.4	1,381,658
	50 < CVPD < 150	182,958.8	1,170,936	31,524.42	47,286.63	10,842	10,842	312,000	111,018.8	312,000	130,416	302,737.5	29,567.36	1218.75	191,149	75,075	19,407.64	1,710,623
	CVPD > 150	260,364.4	1,666,332	44,861.68	67,292.52	15,429	15,429	444,000	157,988.3	444,000	185,592	430,818.75	42,076.63	1734.38	272,020	106,837.5	27,618.56	2,434,349
MIX (15%)	CVPD < 50	152,856.6	978,282	39,838.56	59,757.84	15,985	15,985	276,000	98,208.92	276,000	115,368	267,806.25	26,155.74	1078.13	169,094	66,412.5	17,168.3	1,480,020
	50 < CVPD < 150	186,086.3	1,190,952	48,499.11	72,748.67	19,460	19,460	336,000	119,558.7	336,000	140,448	326,025	31,841.78	1312.5	205,853	80,850	20,900.53	1,801,762
	CVPD > 150	265,837.5	1,701,360	69,284.45	103,926.7	27,800	27,800	480,000	170,798.1	480,000	200,640	465,750	45,488.25	1875	294,075	115,500	29,857.91	2,573,946

Table 8 Cost reduction per km for blended concrete compared to conventional concrete

Concrete blend	% Cost reduction for different traffic levels		
	CVPD < 50	50 < CVPD < 150	150 < CVPD < 450
10% CDA	0.76	1.63	0.15
15% RHA	7.97	8.91	7.82
10% MIX	4.04	4.04	4.04
15% MIX	− 2.79	− 1.08	− 1.47

- RHA blended concrete results in increase in strength as compared to normal concrete. CDA blended concrete always results in decrease in strength as compared to normal concrete. The strength of 10% CDA–RHA mix blended concrete is not observed to be significantly different from normal concrete. However, all blended concrete (at optimum levels of blending) was found to be suitable for construction of low volume concrete pavements typically for rural roads.
- Strength Activity Index of CDA and RHA blended concrete were obtained as 93.03% and 107.97% respectively which exceed the 75% minimum criteria thus concretizing the fact that both RHA and CDA can be used as SCMs. It could be observed that pozzolanic reactions of CDA and RHA in the concrete was low in early ages, but by aging the specimens to 28 days, considerable improvement in strength occurs.
- Durability of blended concrete at optimum level of blending was observed to be more than normal concrete even though their bulk densities were observed to be lower than normal concrete.
- Partial replacement of CDA and RHA was observed to decrease the workability of fresh concrete. Thus, the usage of super-plasticizers may be advocated along with RHA to maintain the desired workability. Moreover, the use of CDA and RHA was observed to increase the initial and final setting time of cement concrete.
- Comparative cost analysis for assessing economic benefit of using SCMs for low volume roads (traffic upto 450 CVPD) showed that partial replacement of cement by CDA, RHA and CDA–RHA mix may result in substantial cost savings. This is over the added benefits of reducing environmental problems related to cement production and CDA and RHA disposal.

Though some interesting observations could be made from the experiments conducted, further exploration with different proportions of CDA–RHA mix blends needs to be done to obtain more economical ternary blending mixes. Also, future studies may be conducted using other conventionally used SCMs such as fly ash to draw comparison with the findings of this study.

Acknowledgements The authors would like to thank Director, NIT Patna Prof. P. K. Jain for funding the experiments conducted for this work from the TEQIP project.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Milad AA, Ali ASB, Yusoff MMI (2020) A review of the utilisation of recycled waste material as an alternative modifier in asphalt mixtures. Civil Eng J 6:42–60
2. Mahdi H, Albayati A (2020) Model development for the prediction of the resilient modulus of warm mix asphalt. Civil Eng Dep 6(4):702–713
3. Balakrishnan R, Saravanan J (2021) Effect of addition of alccofine on the compressive strength of cement mortar cubes. Emerg Sci J 5(2):155–170
4. Bharadwaj DS, Ramesh A (2021)An Experimental Study on Strength Development in Concrete by Incorporating Rice Husk Ash as Replacement to Cement with Recycled Aggregate for Low Volume Roads, 77
5. Givi AN, Rashid SA, Aziz FNA, Salleh MAM (2010) Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete. Constr Build Mater 24:2145–2150
6. Madandoust R, Ranjbar MM, Moghadamb HA, Mousavi SY (2011) Mechanical Properties and durability assessment of rice husk ash concrete. Biosys Eng 110:144–152
7. Chao-Lung H, Anh-Tuan BL, Chun-Tsun C (2011) Effect of rice husk ash on the strength and durability characteristics of concrete. Constr Build Mater 25:3768–3772
8. Venkatanarayanan HK, Rangaraju PR (2015) Effect of grinding of low-carbon rice husk ash on the microstructure and performance properties of blended cement concrete. Cement Concr Compos 55:348–363
9. Shatat MR (2016) Hydration behaviour and mechanical properties of blended cement containing various amounts of rice husk ash in presence of metakaolin. Arab J Chem 9:1869–1874
10. Jamil M, Kaish AB, Raman SN, Zain MF (2013) Pozzolanic contribution of rice husk ash in cementitious system. Constr Build Mater 47:588–593
11. Habeeb GA, Mahmud HB (2010) Study on properties of rice husk ash and its use as cement replacement material. Mater Res 13(2):185–190
12. Zareei SA, Ameri F, Dorostkar F, Ahmadi M (2017) Rice husk ash as a partial replacement of cement in high strength concrete containing micro silica: evaluating durability and mechanical properties. Case Stud Construct Mater 7:73–81
13. Ganesan K, Rajagopal K, Thangavel K (2008) Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete. Constr Build Mater 22:1675–1683
14. de Sensale GR (2006) Strength development of concrete with rice-husk ash. Cement Concr Compos 28:158–160
15. Saraswathy V, Song H-W (2007) Corrosion performance of rice husk ash blended concrete. Constr Build Mater 21:1779–1784
16. de Sensale GR (2010) Effect of rice husk ash on durability of cementitious materials. Cement Concr Compos 32:718–725
17. Rayaprolu VPK, Raju PP (2012) Incorporation of cow dung ash to mortar and concrete. Int J Eng Res Appl (IJERA) 2(3):580–585

18. Samson D, Moses OT (2014) Investigating the pozzolanic potentials of cowdung ash in cement paste and mortars. Civil Environ Res 6(8):110–117
19. Omoniyi T, Duna S, Mohammed A (2014) Compressive strength characteristic of cow dung ash blended cement concrete. Int J Sci Eng Res 5(7):770–776
20. Kumar PT, Reddy RH, Bhagavanulu D (2015) A study on the replacement of cement in concrete by using cow dung ash. Int J Sci Eng Appl Sc (IJSEAS) 1(9):314–327
21. Thakur D, Thakur S, Pal N, Kasbe P, Heggond S (2019) Effect of cow dung on physical properties of concrete. Int Res J Eng Technol (IRJET) 6(3):4470–4472
22. Familusi AO, Adekunle AA, Badejo AA, Olomo RO (2018) Waste valorisation: use of cow dung ash as a partial replacement for cement in sandcrete blocks. In: International Conference on STEM, Abeokuta
23. Suresh A, A. M, Kumar K, Ashik M, Joy A (2019) To study the mechanical properties of cow dung ash modified concrete. Int J Sci Eng Res, 10(5)
24. Dhaka JK, Roy S (2015) Utilization of fly ash and cow dung ash as partial replacement of cement in concrete. Int J Civ Struct Eng 6(1):34–39
25. A. C. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete, West Conshohocken, PA: ASTM International (2005)
26. T. C. DTRL/GEN/0609191919 (2019) Test report, delta testing and research laboratories, New Delhi
27. T. C. 50–280318–04 (2018) Test certificate. AES Laboratories, Noida
28. I (2019) Concrete mix proportioning-guidelines, New Delhi: Bureau of Indian Standards
29. IS:456 (2000) Plain and reinforced concrete – code of practice, New Delhi: Bureau of Indian Standards
30. I (2017) Guidelines for cement concrete mix design for pavements, New Delhi: Indian Roads Congress
31. ASTM C191 (2019) Standard test methods for time of setting of hydraulic cement by vicat needle, West Conshohocken, PA: ASTM International
32. ASTM C187 (2011) Standard test method for normal consistency of hydraulic cement, West Conshohocken,PA: ASTM International
33. 5. IS (2018) Methods of tests for strength of concrete. bureau of indian strandards, New Delhi
34. ASTM C293/C293M (2016) Standard test method for flexural strength of concrete (using simple beam with center-point loading), West Conshohocken, PA: ASTM International
35. ASTM C311/C311M (2018) Standard test methods for sampling and testing fly ash or natural pozzolans for use in portland-cement concrete, West Conshohocken, PA: ASTM International
36. ASTM C597 (2016) Standard test method for pulse velocity through concrete, West Conshohocken, PA: ASTM International
37. (2019) A. C. Standard test method for electrical indication of concrete's ability to resist chloride ion penetration, West Conshohocken, PA: ASTM International
38. (2014) I. Guidelines for the design and construction of cement concrete pavements for rural roads, New Delhi: Indian Roads Congress
39. Huang H, Gao X, Wang H, Ye H (2017) Influence of rice husk ash on strength and permeability of ultra-high performance concrete. Constr Build Mater 149:621–628
40. Ahmadi MA, Alidoust O, Sadrinejad I, Nayeri M (2007) Development of mechanical properties of self compacting concrete contain rice husk ash. Int J Civil Environ Eng 1(10):100–103