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The optimal substitute for rice husk ash required to improve the strength and durability of concrete

ABSTRACT

The increasing environmental impact and high energy consumption associated with ordinary Portland cement (OPC) production have encouraged the development of sustainable supplementary cementitious materials (SCMs) derived from industrial and agricultural wastes. Rice husk ash (RHA) is an agricultural by-product rich in reactive silica and processes significant pozzolanic potential. Therefore, the influence of rice husk ash (RHA) on the properties of fresh and hardened concrete areexperimentally examined in this study. To verify the effect of RHA, two series of concrete mixtures were prepared using two different types of cement, CEM I 42.5R and CEM I 52.5N. For the two concrete series, the cement was partially replaced with RHA at replacement levels of 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, and 40% by mass. The performances of concrete mixtures were evaluated in terms of workability, compressive strength, splitting tensile strength, and chloride penetration resistance (chloride diffusion). Chloride diffusion and mechanical properties were performed on concrete aged 28 and 90 days, and furthermore, at 7 days for the compression strength test. The results revealed that increasing RHA content reduces the workability of concrete due to the large specific surface area and porosity of the RHA particles. However, moderate substitution rates significantly improve the mechanical properties and the chloride penetration resistance due to the contribution of RHApozzolana in formation additional calcium silicate hydrates (C-S-H). The highest resistance to chloride diffusion was acquired at 40% RHA, for concrete made with CEM I 42.5R and CEM I 52.5N. For both types of cement, the tensile and compressive strengths of the concrete were obtained at a RHA rate of 15%, at ages of 28 days and 90 days. Whereas the highest compressive strength at age of 7 days was obtained with RHA rate of 5%. The decrease in strength of concrete with increase the percentage of RHA could be related to that the extra RHA becomes to act as inert filler instead of reactive pozzolana. Therefore, the cement-fine aggregate ratio is decreased and the concrete strength decrease as well.

Keywords: *Cement, compressive strength, tensile strength, workability, chloride diffusion, supplementary cementitious material*

1. INTRODUCTION

Cement is an essential constituent of concrete; however, its manufacturing process is associated with high energy consumption and substantial carbon dioxide (CO_2) emissions resulting from limestone calcination and fuel combustion during clinker production. The cement industry is therefore recognized as one of the major contributors to global greenhouse gas emissions. Consequently, considerable research has focused on the development of sustainable cementitious materials through the incorporation of supplementary cementitious materials (SCMs), which can partially replace ordinary. Portland cement (OPC) while maintaining or improving concrete performance [1]. Among the potential SCMs, agricultural waste-derived materials have attracted increasing attention due to their environmental benefits, availability, and pozzolanic potential [2].

Rice husk is an agricultural by-product generated during rice milling, representing approximately 20% of the total rice grain weight. The uncontrolled disposal or open burning of rice husk creates significant environmental concerns. When rice husk is combusted under controlled temperatures, typically between 500–700°C, the resulting rice husk ash (RHA) contains a high

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amount of reactive amorphous silica (SiO_2), which can exceed 85–90% depending on combustion conditions and processing methods [3]. The pozzolanic reactivity of RHA is strongly governed by the silica phase composition, particle fineness, specific surface area, and loss on ignition (LOI). Controlled burning conditions promote the formation of amorphous silica, whereas excessive combustion temperatures may transform silica into crystalline forms such as cristobalite and tridymite, which exhibit significantly lower pozzolanic activity [4–7]. Additionally, grinding treatment increases the surface area and enhances the reactivity of RHA particles by improving their dispersion within the cement matrix.

In Portland cement systems, hydration of clinker minerals, particularly tricalcium silicate (C_3S) and dicalcium silicate (C2S), produces calcium silicate hydrate (C–S–H) gel and calcium hydroxide (Ca $(OH)_2$). The C–S–H phase is primarily responsible for strength development [8], while calcium hydroxide contributes minimally to mechanical performance and may negatively influence durability. The amorphous silica present in RHA reacts with the liberated calcium hydroxide through a secondary pozzolanic reaction to generate additional C–S–H gel, according to the simplified reaction:

$$SiO_2 + Ca(OH)_2 + H_2O \rightarrow C\text{-}S\text{-}H$$

This secondary hydration mechanism contributes to pore refinement, matrix densification, and reduction in capillary porosity [9]. Moreover, the ultrafine nature of RHA particles promotes a micro-filler effect by filling voids between cement grains and aggregates, resulting in improved particle packing density and a denser interfacial transition zone (ITZ) [10]. The combined filler and pozzolanic effects can significantly enhance compressive strength, reduce permeability, improve resistance to chloride penetration, and mitigate durability-related deterioration mechanisms. Despite these advantages, the incorporation of RHA may also influence fresh concrete properties. Due to its porous structure and high specific surface area, RHA generally increases water demand and reduces workability. At higher replacement levels, insufficient cementitious content and delayed hydration may reduce early-age strength development. Therefore, the optimum replacement ratio depends on the balance between pozzolanic reactivity, particle packing effects, and dilution of cement clinker phases [11]

The performance of RHA-blended concrete is also highly dependent on the characteristics of the cement used, particularly cement grade, mineralogical composition, and hydration kinetics. CEM I 52.5N cement typically exhibits higher clinker reactivity and faster hydration rates compared with CEM I 42.5R, resulting in accelerated formation of hydration products and greater early-age strength development [12]. These differences may significantly influence the interaction between RHA and hydrated cement phases, affecting the rate of calcium hydroxide consumption, microstructural evolution, and long-term strength gain. Furthermore, variations in cement fineness and tricalcium silicate content may alter the synergistic behavior between OPC and RHA in blended systems [13].

Although numerous investigations have examined the utilization of RHA as a partial cement replacement material, most studies have focused on a single cement type and limited replacement levels. Comparative evaluations involving different OPC grades under identical curing, mixing, and testing conditions remain limited. In particular, insufficient attention has been given to understanding how cement grade influences the pozzolanic efficiency and microstructural performance of RHA-containing concrete. Therefore, the present study aims to systematically investigate the effects of varying RHA replacement ratios on the fresh, mechanical, and durability properties of concrete produced using CEM I 42.5R and CEM I 52.5N cement grades. The study further evaluates the combined influence of cement grade and RHA incorporation on hydration behavior, compressive strength development, pore structure refinement, and overall concrete performance.

2. EXPERIMENTAL PROGRAM

2.1. Materials

2.1.1. Rice husk ash (RHA)

Rice husk was collected from a local rice mill in Al Qadisya governorate - Iraq and incinerated in a kiln under controlled conditions to produce rice husk ash. After cooling, the ash was ground to a fine particle size. The resulting RHA was then graded and sieved according to relevant standards of SCMs such as BS EN 450-1: 2012 [14]. The chemical analysis confirmed that the ash contained a high proportion of silica, alumina, and iron oxide, indicating its pozzolanic nature. Chemical composition and physical properties are presented in Table 1.

Table 1. Physical Properties, chemical properties, and Loss on ignition of RHA

Physical Properties	Specific surface area (m^2/kg)			793					
	Mean particle size (µm)			11.89					
	Amorphous Structure			Controlled burning between 550°C to 600°C for 90 minutes					
Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	P_2O_5	SO_3	MnO	L.O.I*
Result %	95.17	1.081	0.109	0.782	1.201	0.598	0.039	1.004	1.09

*L.O.I: Loss on ignition

It was essential to know the shape, size and morphological characteristics of the RHA particles used to understand and explain some of the results on flow, strength, and shrinkage. The microstructure of RHA sample was investigated with a scanning electron microscopy (SEM ZEISS model Gemini SEM500). The scanning electron micrographic (SEM) observation of 5.00KX (500 times magnification) with a resolution of 10µm and 2µm for RHA sample is presented in Figure 1. Microscopic observation of RHA ash revealed the presence of small particles formed by deformation or collapse of the structure in some parts of the inner shell of RHA after burning at 550°C – 600°C for 90 minutes. Additional nano pores and micro pores,ranging in size from 0.060 to 7.80 µm, are observed after fracturing some parts of RHA sample. The intra particle mesoporous and macrospores of the RHA sample generate the remarkably high specific surface area of this material.

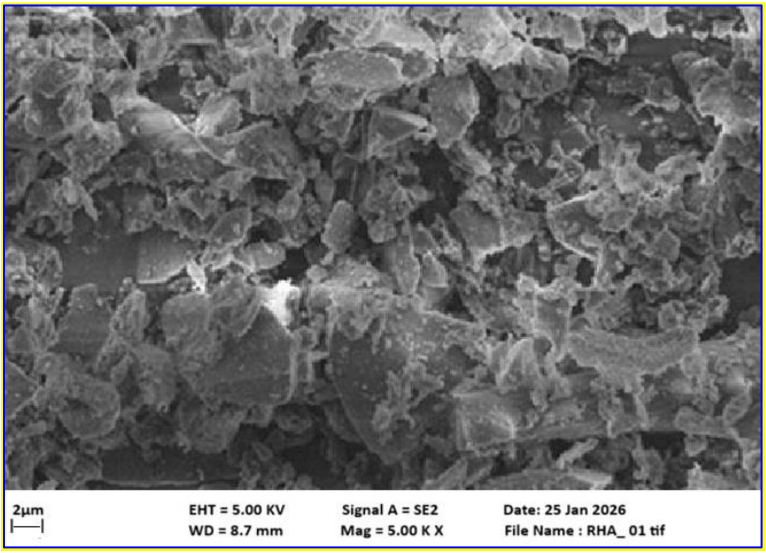

Figure 1. Scanning electron micrograph (SEM) of RHA particles ground for RHA at 2µm.

2.1.2. Cement

Ordinary Portland cement (Tasluja) conforming to Iraqi Standard IQS 5:2019 Type I and EN 197-1:2011[15], with a strength class of CEM I 42.5R and CEM I 52.5N, were used in this study. The chemical compositions supplied by the factory are listed in Table 2.

*Table 2: Properties of Cement types used in the study**

Chemical composition %		CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	Cl^-	L.O.I
Cement Type	CEM I 42.5R	64.3	21.8	4.92	4.27	2.1	0.71	0.19	1.05	0.12	1.07
	CEM I 52.5N	65.7	21.82	5.36	3.74	1.19	0.25	0.51	0.86	0.015	0.2

*Results are according to the Tasluja cement manufacture company.

2.1.3. Aggregates

The coarse aggregate used had a particle size between 4.75 mm and 20 mm, while natural river sand was employed as the fine aggregate with particle size less than 4.75 mm. All aggregates properties conformed to the requirements specified in applicable standards, BS EN 12620:2002+A1:2008[16].

2.2. Mix Proportions

Concrete mixtures were designed for a target compressive strength of 50 MPa at 28 days with a constant water-to-binder ratio of 0.45. The quantities of water (207 kg/m^3), fine aggregate (785 kg/m^3), coarse aggregate (800 kg/m^3), and superplasticizer (0.25% by cementitious mass) were maintained constant for all mixtures. For clearer presentation and discussion, each mixture was assigned a unique mix ID based on cement grade and RHA replacement ratio. The control mixture without RHA was identified as C42-R0 or C52-R0 depending on cement grade, while mixtures containing RHA were designated according to replacement percentage.

Table 3: Concrete mixtures proportions employed in this study

Mix Label	M0	M5	M10	M15	M20	M25	M30	M35	M40
RHA%	0	5	10	15	20	25	30	35	40
RHA (kg)	0	23	46	69	92	115	138	161	184
Cement (kg)	460	437	414	391	368	345	322	299	276
If the mix label is followed by "-R", it indicates CEM I 42.5R; if it is followed by "-N", it indicates CEM I 52.5N.									

2.3. Experimental tests

The experimental work included the following tests:

- **Workability:** to measure the workability of concrete mixtures, slump test was employed by Abram cone according to BS EN 12350-2:2009[17].
- **Compressive strength:** The compressive strength test was performed in according with BS EN 12390-6:2009 [18]. The test was carried out at three different ages of 7, 28, and 90 days and that for each of the nine mixes (the control and those of RHA). 3 concrete cubes of 150mm×150mm×150mm were cast for each time of testing.
- **Tensile strength (splitting test)**: The test wasdone according to BS EN 12390-3:2009[19]. Concretecylinders specimens of 100mm diameter × 200mm height, were prepared for each time of testing. Since concrete has low tensile strength, the test was performed only at late ages of 28 and 90 days for each of the nine mixes. At each time of testing three specimens were examined and tested.
- **Chloride Diffusion Test:**Chloride Migration test was performed according to NT BUILD 492-1999 [20]. In this test, a disc of 100mm diameter × 50mmheight was achieved by cutting the cylinders specimens of 100mm diameter × 200mm height by saw according to the standard of this test, as shown in Figure 2.

Figure 2. Preparation of samples (50mm thickness) for chloride diffusion test by cutting concrete cylinder by saw

In this test, the applied electrical field was variable between 24 to 96 hrsin all the experiments according to resistance of concrete.After testing three concrete samples using the rapid chloride migration (RCM) test set-up, three samples were split and sprayed by $AgNO_3$solution with 0.1%, a colorimetric indicator for chlorides.

AgCl, being the product of the reaction of $AgNO_3$ with chlorides, has a white color, while AgOH (which is later transformed to Ag_2O), formed in the chloride-free regions of sample, is brownish. Therefore, the boundary between the regions with and without chlorides becomes clearly visible and the chloride penetration depth can be measured as shown in Figure 3.

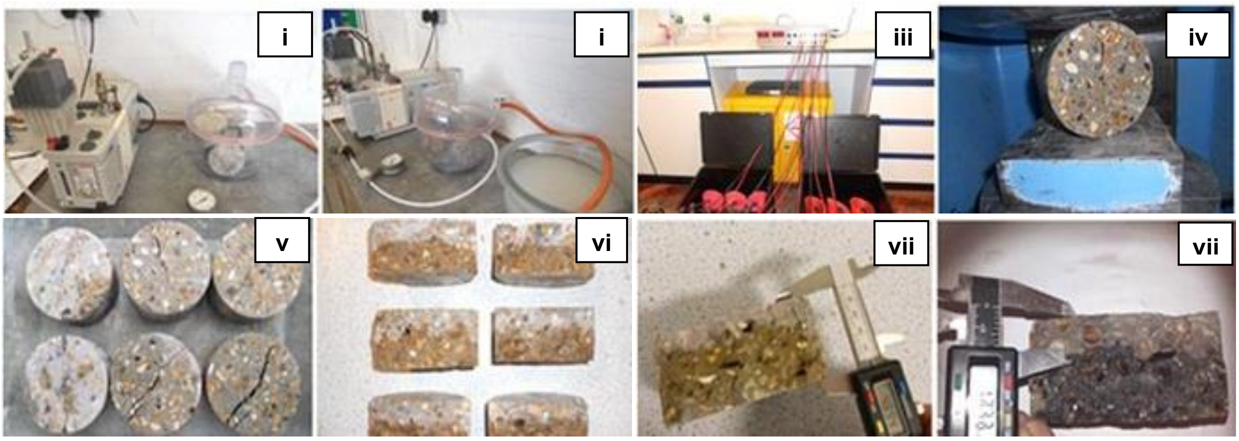

Figure 3. Preparation set up test and determine the non-steady-state migration coefficient efficiency of OPC and RHA concrete mixtures. (i) Vacuuming the samples in empty container for 3h in. (ii) Vacuuming the samples into Ca $(OH)_2$ solution for 1h. (iii) Treating the samples with Ca $(OH)_2$ solution for 1h, (iv) set up the samples using NT BUILD 492 method. (v) splitting the samples into two halves. (vi) samples after being split in half, (vii) samples after being sprayed by $AgNO_3$, (viii) determining the depth of chloride diffusion within the samples

3. RESULTS AND DISCUSSION

3.1. Workability

The incorporation of rice husk ash in mixtures significantly affects the total surface area of the binder due to the high surface area of RHA which is about twice that of OPC. Therefore, concrete workability decreased progressively with increasing RHA content for mixes of CEM I 42.5R and CEM I 52.5N (see **Figure 4**). As well as, the mixtures incorporating CEM I 52.5N (i.e. from M5-N to M40-N) exhibited lower slump values comparing with those of CEM I 42.5R. This could be related to the fineness of their particles, which increases the surface area and therefore the demand for water. These results indicate that additional water or chemical admixtures may be required to maintain workability in RHA-modified concrete.

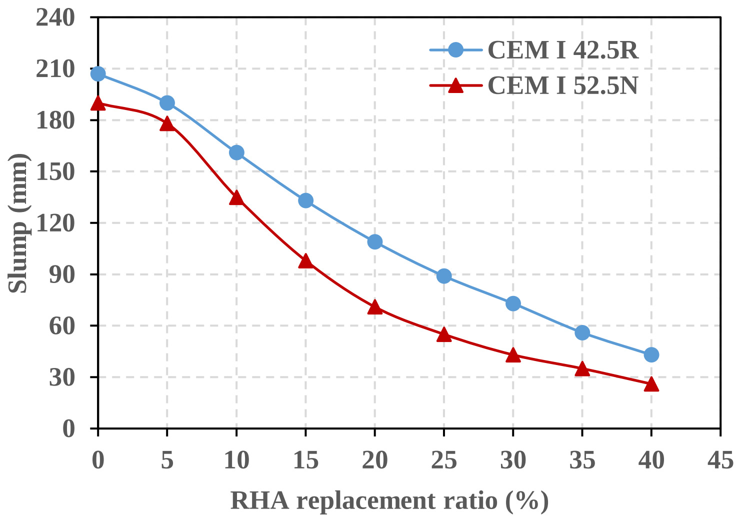

Figure 4. Workability of fresh concrete mixtures with different RHA replacement ratios by cement mass

3.2. Compressive Strength

For the both type of cement, the compressive strength results revealed that at early-age, of 7 days, M5, M10, M15, M20 exhibited an increase in compressive strength. However when the percentage of RHA is increased up to 40%, M40, the mixes exhibited a reduction in compressive strength compared to the control mix, M0, (see **Figure 5**). However, with continued curing for late-ages, of 28 and 90 days, the compressive strengths were improved with increasing the percentage of RHA to reach its maximum value in M15-N and M15-R. Thus, the optimal replacement ratio of approximately 15% has been identified for all cement grades, enabling satisfactory strength performance. This result confirms that of Rasoul et al [4] where concrete produced with OPC grades CEM I 42.5R and CEM I 52.5N demonstrated better compatibility with RHA than OPC32.5R [4]. This development in strength could be related to ongoing pozzolanic reactions [1, 4].

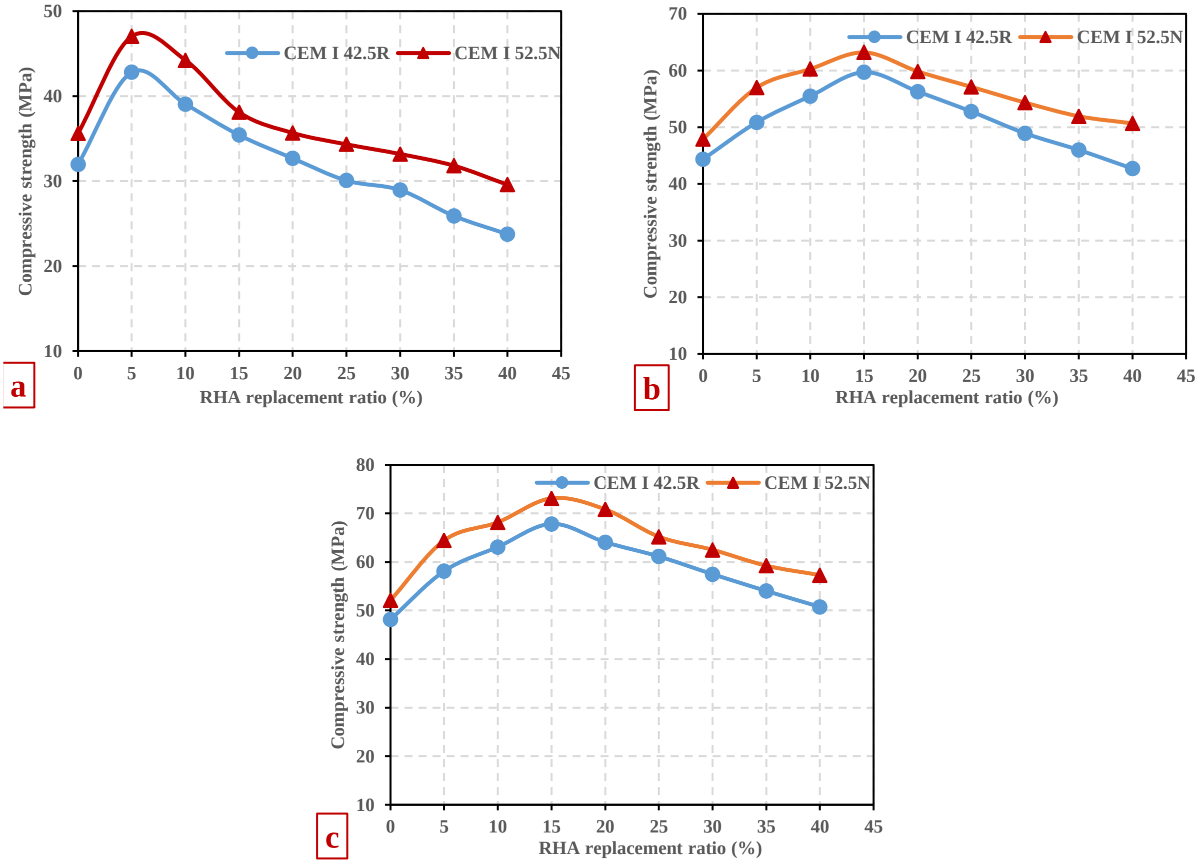

Figure 5. Compressive strength of concrete vs. RHA replacement ratios by cement mass for two types of cement, (a) at age of 7 days, (b) at age of 28 days, and (c) at age of 90 days

3.3. Tensile Strength

The results of splitting tensile strength are plotted in Figure 6 at curing age 28 and 90 days. It could be seen that the splitting tensile strength results have the same tendency as those of compressive strength.

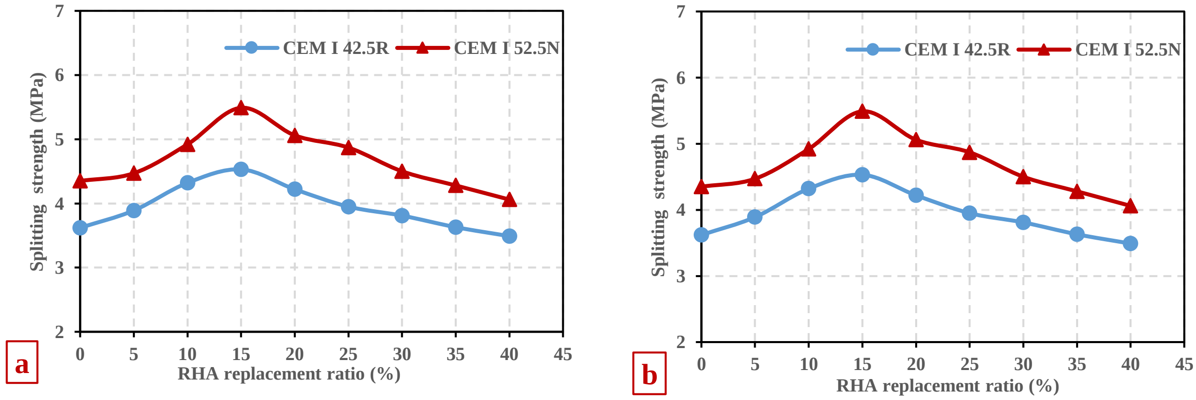

Figure 6. Splitting strength vs. RHA replacement ratios by cement mass for two types of cement, (a) at age of 28 days and (b) at age of 90 days

The splitting tensile strength of the tested specimens ranged from 3.49MPa (M40-R) to 4.53MPa (M15-R) and from 3.98 MPa (M40-N) to 5.49MPa (M15-N). Compared to the control samples, M0-R and M0-N, of the same age, it is evident that the splitting tensile strength at 90 days was increased for M15-R by 25.14% and for M15-N by 52.66%. This significant development in splitting tensile strength of RHA-CEM I 52.5N can be attributed to the highly reactive silica, the fineness of its particles, and to the purity of CEM I 52.5N [1, 3]. Indeed, the amorphous silica of RHA, gradually consumes the Ca(OH)2 formed during the hydration of Portland cement . Therefore, the characteristics of the constituent cementitious materials (cement type, RHA properties) considerably influence the strength development of concrete and require greater attention when RHA is used as a supplementary cementitious material with cement which is already contents a percentage of limestone or fly ash.

3.4. Durability under Chloride Attack (Migration Diffusion Coefficient)

The non-steady-state migration coefficient of chloride (D_{nssm}) of concrete specimens at 28 and 90 days were computed and presented in **Figure 7**. The results indicated that increasing the RHA replacement ratio enhances the resistance of concrete to chloride ion diffusion for both cement types, CEM I 42.5R and CEM I 52.5N. Moreover, it could be seen that extending the wet curing period to 90 days has reduced the diffusion compared to the 28-day curing. This finding is consistent with that reported by Gastaldini et al. [21] and Saraswathy and Song [22] which confirms the effect of longer curing period on improving the diffusion resistance of RHA concrete.

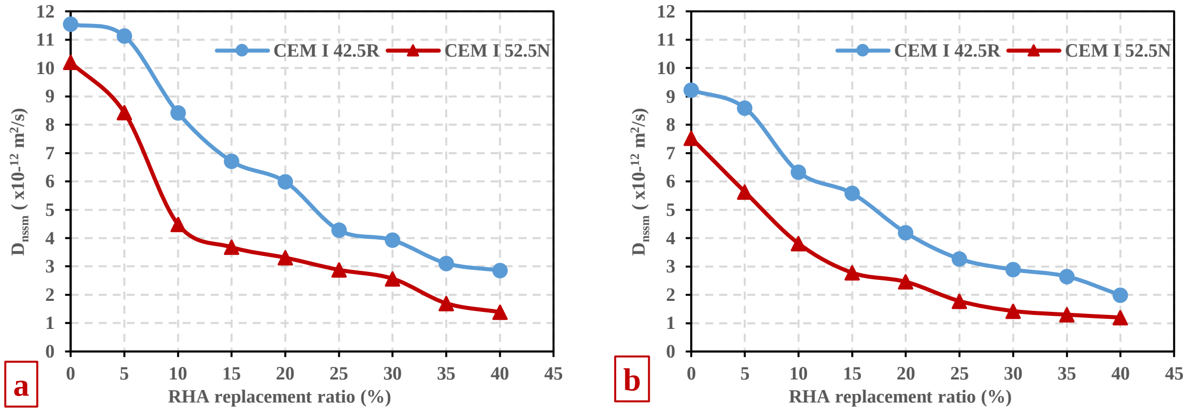

Figure 7. Effect of RHA replacement ratios by cement mass to the depth of chloride diffusion (a) at age of 28 and (b) at age of 90 days

As an example, the $D_{nssm}$of 40% RHACEM I 42.5R mixture was 2.86×10^{-12}m^2/s when cured for 28days, and became 1.99×10^{-12}m^2/s as curing extended to 90 days. This effect is more clear with RHA- CEM I 52.5N concrete, where at 40% replacement ratio the D_{nssm} was 1.39×10^{-12}m^2/s when cured for 28days, and became 1.20×10^{-12}m^2/s as curing extended to 90 days compare to 9.22 ×10^{-12}m^2/s of controlled concrete at age of 90 days. These results highlight the significant improvement in chloride diffusion resistance achieved through both higher curing duration and RHA incorporation, confirming that the long-term curing results in higher resistance to chloride permeability [21-23].

The decrease in chloride diffusion could be related to a continued reactionof RHA silica with $Ca(OH)_2$ resulting from cement hydration [24]. The fine particles of RHA causes segmentation of large pores and increases nucleation sites for precipitation of hydration products in cementitious paste [25]. Increasing the reaction products and improving the porous structure of the cementitious paste, reduces the diffusion of calcium hydroxide within it[26].

3.5. Microstructural Interpretation

SEM observations revealed that the RHA particles possess irregular porous surfaces with high fineness and internal pores. These characteristics contribute to enhanced particle packing and increased nucleation sites for hydration products. The formation of additional secondary C–S–H gel led to a denser microstructure and reduced pore connectivity, which explains the improvement in compressive strength and chloride diffusion resistance observed in mixtures containing 10–20% RHA [25]. The decrease in chloride diffusion could be related to a continued reaction of RHA silica with Ca $(OH)_2$ resulting from cement hydration [27]. The fine particles of RHA causes segmentation of large pores and increase nucleation sites for precipitation of hydration products in cementitious paste [28-29]. Increasing the reaction products and improving the porous structure of the cementitious paste, reduces the diffusion of calcium hydroxide within it [30, 31].

4. CONCLUSIONS

Since the waste management is one of the most important problems, the demand of using green materials in building construction was raised. Therefore, the objective of the current study was to determine the optimal percentage of incorporation of an eco-friendly material namely rice husk ash (RHA) in concrete producing. This work involved replacing part of cement with RHA in varying proportions and for two grades of cement; CEM I 42.5R and CEM I 52.5. To verify the effect of RHA, compressive and tensile strength, and chloride penetration resistance were investigated for different replacement percentages of RHA. The obtained results could be summarized as follows:

- At late ages of 28 days and 90 days, the results showed that using RHA as a partial replacement of cement (CEM I 42.5R and CEM I 52.5N) ispositively affects the compressive and the tensile strength to reach its maximum value at 15% RHA. This improvement in strength is attributed to the pozzolanic activity of RHA, which promotes the formation of additional calcium silicate hydrate (C-S-H). The resulting fine C-S-H gel fills the capillary pores, increase the density and thus increase the strength of the concrete. With increasing the percentage of RHA (more than 15%), the strength begins to decrease. This decreasing in strength is related to that at high percentage of RHA replacement (with the supplementary materials already present in the cement)), shift from acting as reactive pozzolanic components to functioning primarily as inert fillers. . Consequently, the cement-fine aggregate ratio is reduced, which means that the reactive cementitious binder becomes insufficient to coat the aggregate particles, resulting in a decrease in the concrete strength.
- At early age, of 7 days, incorporating RHA enhances the compressive strength where the maximum value is achieved at 5% RHA replacement of cement (CEM I 42.5R and CEM I 52.5N). However, when the percentage of RHA replacement is increased, the compressive strength of concrete decreases. In addition, for more than 20% RHA replacement, the compressive strength becomes even lower than the reference mix where there is no RHA replacement.
- Chloride ion diffusion resistance was improved substantially with the incorporation of RHAand thus enhances the durability of concrete. The highest resistance to chloride diffusion was acquired at 40% results RHA. This impact is more pronounced in CEM I 52.5N, confirming the significant influence of RHA properties on the development of chloride diffusion resistance in pure cement systems. The improvement in chloride diffusion resistance of RHA concrete is related to the reaction of the fine, amorphous pozzolanic silica particles of the rice husk ash. Indeed, the additional formation of hydrated calcium silicate (C-S-H) fills the capillary pores, reducing porosity and limiting pore continuity. As a result, permeability decreases and chlorine diffusion within the concrete is reduced.
- Depending on the obtained results of compressive and tensile strength, and of chloride diffusion, the optimal recommended replacement of RHA is 15%. However, the exact recommended ratio may vary depending on the cement grade and on the specific performance requirements.
- The workability decreases with increasing the RHA replacement ratio. This may be related to the large surface area of rice husk ash, which increases water demand and thus reduces the workability.

5. REFERENCES

[1] S.Samad, A.Shah (2017) Role of binary cement including Supplementary Cementitious Material (SCM), in production of environmentally sustainable concrete: International Journal *of Sustainable built environment*, 6, 663-674 https://doi.org/10.1016/j.ijsbe.2017.07.003.

[2] S.Maji, D. H.Dwivedi,N.Singh,S.Kishor&M.Gond (2020) Agricultural waste: Its impact on environment and management approaches. *In Emerging eco-friendly green technologies for wastewater treatment* 329-351.

[3] S.K.Antiohos, V.G.Papadakis and S.Tsimas (2014)Rice husk ash (RHA) effectiveness in cement and concrete as a function of reactive silica and fineness. *Cement and concrete research*, 61,20-27. https://doi.org/10.1016/j.cemconres.2014.04.001.

[4] B.I.Rasoul, F.K. Günzel, and M.I.Rafiq(2017) Effect of rice husk ash properties on the early age and long term strength of mortar. In High Tech Concrete: Where Technology and Engineering Meet: *Proceedings of the 2017 fib Symposium, held in Maastricht, 2017*, 207-214.

[5] D.G.Nair, A.Fraaij, A.A. Klaassen and A.P.Kentgens(2008) A structural investigation relating to the pozzolanic activity of rice husk ashes. *Cement and concrete research*, *38*, 861-869. https://doi.org/10.1016/j.cemconres.2007.10.004.

[6] J.Payá, J.Monzó, M.V.Borrachero, E.Peris-Mora, and L.M.Ordóñez(2000) Studies on crystalline rice husk ashes and the activation of their pozzolanic properties. *In Waste Management Series*, 1, 493-503. https://doi.org/10.1016/S0713-2743(00)80060-4.

[7] A.Salas, M.A.Ospina, ,S.Delvasto, and R.Mejía de Gutiérrez (2007) Study on the pozzolanic properties of silica obtained from rice husk by chemical and thermal process. *physica status solidi, 4*, 4311-4318. https://doi.org/10.1002/pssc.200675924.

[8] Ö.Cizer, K.Van Balen, J.Elsen, D.Van Gemert, J.Marchand, B.Bissonnette, R.Gagné, M.Jolin, and F.Paradis(2006) Carbonation and hydration of calcium hydroxide and calcium silicate binders with rice husk ash. *In 2nd International RILEM Symposium*. Rilem Publications SARL; France.

[9] A.P.Vieira, R.D.Toledo Filho, L.M. TavaresandG.C.Cordeiro(2020) Effect of particle size, porous structure and content of rice husk ash on the hydration process and compressive strength evolution of concrete. *Construction and Building Materials*, 236, 117-553. https://doi.org/10.1016/j.conbuildmat.2019.117553.

[10] S.Gupta and H.W.Kua(2020) Application of rice husk biochar as filler in cenosphere modified mortar: Preparation, characterization and performance under elevated temperature. *Construction and Building Materials*, 253,119083. https://doi.org/10.1016/j.conbuildmat.2020.119083.

[11] D.O.Nduka, B.J.Olawuyi, O.O. Joshua and I.O.Omuh(2022) A study on gel/space ratio development in binary mixture containing Portland cement and meta-illitecalcined clay/rice husk ash. *Gels*, 8, 85. https://doi.org/10.3390/gels8020085.

[12] M.B.Revuelta(2021) Construction materials: Geology, production and applications. *Springer Nature*.

[13] J.Wang, F.Jiang, J.Zhou and Z.Mao (2024) The synergistic effect of limestone powder and rice husk ash on the mechanical properties of cement-based materials. *Materials*, 20, 5058. https://doi.org/10.3390/ma17205058.

[14] European Committee for Standardization, BS EN 450-part 1(2012) Fly ash for concrete: Definition, specifications and conformity criteria. *British Standard Institution*.

[15] European Committee for Standardization, BS EN 197-part 1(2011) Cement: Composition, specifications and conformity criteria for common cements. *British Standard Institution*.

[16] European Committee for Standardization, BS EN 12620:2002+A1, (2008)Aggregate of Concrete. *British Standard Institution*.

[17] European Committee for Standardization, BS EN 12350-2 (2019) Slump Test. *British Standard Institution*.

[18] European Committee for Standardization, EN 12390-3:2009 Testing hardened Concrete: Compressive strength of test specimens. *British Standard Institution*.

[19] European Committee for Standardization, EN 12390-6, (2009)Testing hardened Concrete. Tensile splitting strength of test specimens. *British Standard Institution*

[20] Nordic Council minister NT Build 492 (1999) Chloride migration coefficient from non- steady-state migration experiments.

[21] A.L.G.Gastaldini, G.C.Isaia, N.S. Gomes and J.E.K.Sperb(2007) Chloride penetration and carbonation in concrete with rice husk ash and chemical activators. *Cement and Concrete Composites*, 29, 176-180. https://doi.org/10.1016/j.cemconcomp.2006.11.010.

[22] B.A.Tayeh,R.Alyousef, H.Alabduljabbar, A.Alaskar (2021) Recycling of rice husk waste for a sustainable concrete: a critical review. *Journal of Cleaner Production, 312, 127734*. https://doi.org/10.1016/j.jclepro.2021.127734.

[23] V.Saraswathy and H.W.Song (2007) Corrosion performance of rice husk ash blended concrete. *Construction and building materials*, 21, 1779-1784. https://doi.org/10.1016/j.conbuildmat.2006.05.037.

[24] Y.Y. Lim and T.M.Pham (2021) Influence of Portland cement on performance of fine rice husk ash geopolymer concrete: Strength and permeability properties. *Construction and Building Materials*, 300, 124321. https://doi.org/10.1016/j.conbuildmat.2021.124321.

[25] P.Chindaprasirt, P.Kanchanda, A.Sathonsaowaphak and H.T.Cao (2007) Sulfate resistance of blended cements containing fly ash and rice husk ash. *Construction and Building Materials*, *21*, 1356-1361. https://doi.org/10.1016/j.conbuildmat.2005.10.005.

[26] A.O.Kadhum, A.S. Al-Ameeri, and S.J.Edrees(2025) Evaluation of the Effect of Silica Fume on Corrosion and Penetration of Chloride Ions into Green Concrete. In IOP Conference Series: *Earth and Environmental Science 1507*, 012091. IOP Publishing. https://doi.org/10.1088/1755-1315/1507/1/012091.

[27] A.O.Kadhum, A.S.AL-Ameeri, S.J. Edrees and M.I.Rafiq (2025) High-performance eco-friendly concrete with improved strength, chloride ion penetration, and corrosion resistance by the high volume of Ground Granulate Blast Furnace Slag (GGBS). *ZastitaMaterijala*, 66, 845-866. https://doi.org/10.62638/ZasMat1325.

[28] W.Xu, Y.T.Lo, D.Ouyang, S.A.Memon,F. Xing, W.Wang and X.Yuan (2015) Effect of rice husk ash fineness on porosity and hydration reaction of blended cement paste. *Construction and Building Materials*, 89, 90-101. https://doi.org/10.1016/j.conbuildmat.2015.04.03.

[29] P.Chindaprasirt, and S.Rukzon(2008) Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. *Construction and Building Materials*, 22, 1601-1606. https://doi.org/10.1016/j.conbuildmat.2007.06.010

[30] P.K.Mehta (1983) Mechanism of sulfate attack on portland cement concrete. *Cement and Concrete research*, 13, 401-406. https://doi.org/10.1016/0008-8846(83)90040-6.

[31] S.Tang, Y.Wang, Z.Geng, X.Xu, W.Yu, H.A, and J.Chen(2021)Structure, fractality, mechanics and durability of calcium silicate hydrates. Fractal and Fractional, 5, 47. https://doi.org/10.3390/fractalfract5020047.

IZVOD

OPTIMALNA ZAMENA ZA PEPEO OD PIRINČANE LJUSKE POTREBNA ZA POBOLJŠANJE ČVRSTOĆE I IZDRŽLJIVOSTI BETONA

Rastući uticaj na životnu sredinu i visoka potrošnja energije povezana sa proizvodnjom običnog portland cementa (OPC) podstakli su razvoj održivih dodatnih cementnih materijala (SCM) dobijenih od industrijskog i poljoprivrednog otpada. Pepeo od pirinčane ljuske (RHA) je poljoprivredni nusproizvod bogat reaktivnim silicijum dioksidom i ima značajan pucolanski potencijal. Stoga je u ovoj studiji eksperimentalno ispitan uticaj pepela od pirinčane ljuske (RHA) na svojstva svežeg i očvrslog betona. Da bi se potvrdio efekat RHA, pripremljene su dve serije betonskih mešavina koristeći dve različite vrste cementa, CEM I 42.5R i CEM I 52.5N. Za dve serije betona, cement je delimično zamenjen RHA u nivoima zamene od 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% i 40% po masi. Performanse betonskih mešavina su procenjene u smislu obradivosti, čvrstoće na pritisak, zatezne čvrstoće na cepanje i otpornosti na prodiranje hlorida (difuzija hlorida). Difuzija hlorida i mehanička svojstva su merena na betonu starom 28 i 90 dana, a dodatno i na 7 dana za test čvrstoće na pritisak. Rezultati su pokazali da povećanje sadržaja RHA smanjuje obradivost betona zbog velike specifične površine i poroznosti RHA čestica. Međutim, umerene stope supstitucije značajno poboljšavaju mehanička svojstva i otpornost na prodiranje hlorida zbog doprinosa RHApucolana u formiranju dodatnih kalcijum silikatnih hidrata (C-S-H). Najveća otpornost na difuziju hlorida je dobijena pri 40% RHA, za beton napravljen sa CEM I 42.5R i CEM I 52.5N. Za obe vrste cementa, zatezna i pritisna čvrstoća betona su dobijene pri RHA stopi od 15%, pri starosti od 28 dana i 90 dana. Dok je najveća pritisna čvrstoća pri starosti od 7 dana dobijena sa RHA stopom od 5%. Smanjenje čvrstoće betona sa povećanjem procenta RHA može biti povezano sa time da dodatni RHA počinje da deluje kao inertno punilo umesto reaktivnog pucolana. Stoga se odnos cementa i finog agregata smanjuje, a samim tim i čvrstoća betona se smanjuje.

Ključne reči: *Cement, čvrstoća na pritisak, čvrstoća na zatezanje, obradivost, difuzija hlorida, dodatni cementni materijal*

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