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Chloride Ingress Resistance of Rice Husk Ash Based Green Concrete Composites Containing Steel Fibres

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Fibre reinforced concrete (FRC) is a conventional concrete mix that contains hydraulic cement, fine and coarse aggregate and discontinuous randomly distributed discrete fibre in concrete mix. Research has revealed that inclusion of fibre in concrete can enhance its performance characteristics in terms of durability, ductility, strength as well as energy absorption properties. Steel fibre concretes without Rice Husk Ash (RHA) have been successfully used for crack control in many structural applications. With the increasing amount of waste generation from various processes, there has been a growing interest in the utilization of waste in production of building materials to achieve potential benefits. This leads to sustainable, green and eco-friendly construction by reducing the price of components compare to disposing of the materials. This study examines the chloride resistance performance of green concrete composites containing steel fibre and 15% RHA. Four volume fractions of fibre from 0 to 2% at an interval of 0.5% and fibre length of 20 mm were used for CEM 1 (42.5 N) mixtures. The concrete was designed using the Department of Environment (DOE) mix design method to achieve a 28 days target strength of 30 N/mm^2. Chloride resistance was assessed at 7, 28 and 56 days. The result shows that incorporation of steel fibre in RHA based concrete reduce the workability of concrete owning to its nature and affinity for water due to the presence of silica it contains. It was observed that incorporation of 1.0% steel fibre and 15% RHA in concrete provide a synergetic improvement on chloride resistance (durability) and strength when compared with control mix. The study recommends the utilization of steel fibre along with RHA in the production of a new alternative concrete composite that can resist chloride ingress in concrete composite.

Keywords: Cement, Chloride resistance, Fibre reinforced concrete, Rice husk ash, Steel fibres

INTRODUCTION

The use of industrial by-products has the potential to deliver economic paybacks such as preserving raw resources and avoiding negative environmental consequences connected with raw material acquisition and processing. The concept of sustainability in the building industry supports the use of waste goods to substitute conventional resources such as fine and coarse aggregate, cement, and fibrous materials (Mohammadhosseini *et al*., 2019). Previous research by Ogunbode and Akanmu (2012), Zareei *et al*. (2017), Khongpermgoson *et al*. (2019), Hamada *et al*. (2018), Fapohunda *et al*. (2017) and Mohammadhosseini *et al*. (2019) established that several agricultural and industrial waste materials such as cassava peel ash, ground coal bottom ash, calcium carbide, rice husk ash, The method required in the manufacturing of OPC requires a large amount of money and a lot of energy, whereas replacing OPC with additional cementing ingredients can save money and energy (Khongpermgoson *et al*., 2019). It is widely known that OPC manufacturing has also had a negative impact on the environment due to the increased amount of carbon dioxide in the atmosphere. China produced the most cement in the world in 2019, with an estimated 2.2 billion metric tons. This quantity accounts for more than half of global cement output (Datis Export Group, 2020). Global cement output is anticipated to rise from 3.27 billion metric tons in 2010 to 4.83 billion metric tons by 2030. (Datis Export Group, 2020; Elbaz *et al*., 2019). A significant reduction in Portland cement production by using agricultural and industrial waste ash as pozzolan would result in a cleaner and safer environment. Emissions from Portland cement manufacturing not only degrade air quality but also endanger human health. This pollution has both local and global environmental consequences, including global warming, ozone layer depletion, acid rain, biodiversity loss, and decreased crop production (Datis Export Group, 2020).

Globally, significant efforts are being made to use natural waste and by-products as extra cementing ingredients to improve the characteristics of cement concrete. RHA (rice husk ash) is one such substance. RHA is a by-product of the rice industry. Rice husk ash is a highly reactive pozzolanic substance created by the controlled combustion of rice husk (Sravanthi and Ismail, 2016). RHA also contains chemical compositions that are similar to pozzolanic material. It is composed of amorphous Si, Al, and Fe oxides, as well as other essential qualifying characteristics specified by ASTM C 618 (2015). As a result, the study intended to use RHA as a partial replacement for cement in the production of fibre reinforced concrete.

Many researchers, including Yazici and Arel (2012), Lanzerstorfer (2018), and Hsu *et al*. (2018), have demonstrated that the particle size of pozzolan has a significant effect on the reaction and strength of the binder (As a result, RHA was ground to increase the fineness before using as a binder in fibre reinforced concrete to improve its strength and reaction). Nowadays, many concrete buildings along the beach, such as bridges, jetties, ports, and hotels, are erected and are constantly exposed to chloride salt. It was critical to develop concrete that was resistant to chloride migration. Many researchers discovered that replacing OPC with pozzolanic materials might minimize chloride penetration in concrete (Chindaprasirt *et al*., 2007; Moffatt *et al*., 2017; Argiz *et al.,* 2018).

For many years, fibres have been widely employed in different building and civil engineering projects. Toughness increases as post-cracking tensile and flexural strength of fibre concrete improves. The primary advantage of using fibers is the reduction of cracking. Steel fibres are primarily utilized for fracture management in ductile construction. Steel fibre volumes as little as 0.5 percent were effective in a variety of applications such as concrete pavements, slabs, and tunnel linings (Mandhkan *et al*., 2012; Soutsos *et al*., 2012; Buratti *et al.,* 2013; Falkner & Henke, 1998). In low volume concentrations, fibres have the effect of secondary reinforcement for concrete because they reduce cracking but do not add to load bearing capacity. According to the literature, the improvement in compressive strength caused by low steel fibre content is relatively modest. Steel fibres had a significantly greater effect on splitting tensile and flexural strengths (Thomas & Ramaswamy, 2007; Song & Hwang, 2004; Sivakumar & Santhanam, 2007; Yazc *et al*., 2007; Koksal *et al*., 2008; Atis & Karahan, 2009).

The influence of steel fibres on strength becomes increasingly important as the fibre volume grows from 0.5 percent to 1 percent or 1.5 percent. This increase in fibre content is represented more immediately in tensile strength measurements (Sivakumar & Santhanam, 2007; Yazc *et al.*, 2007; Koksal *et al.*, 2008; Atis & Karahan, 2009). However, other findings show that steel fibre insertion reduces compressive (Altun *et al*., 2007; Kayali, 2004) and flexural strength (Atis & Karahan, 2009). Previous research on steel fibre reinforced concrete with RHA is limited when compared to steel fibre reinforced concrete without RHA. Several investigations have shown that fibre insertion in concrete can change some of the physical characteristics of the material. Steel fibres reduced fast chloride permeability significantly, according to Gutierrez *et al.,* (2005) and Sun *et al*. (2001). Fibres as demonstrated in the literature, can influence the physical characteristics of concrete, such as porosity and permeability. Such effects can be important for aggressive agent penetration and can be detrimental to concrete durability.

The significance of this paper is based on investigating the chloride ingress resistance property of galvanized straight steel fibre concrete, which is widely used in various applications such as slabs, pavements, tunnel linings, pipes, and so on and has proven to be effective in crack control with 15% RHA. On the other hand, research on chloride ingress resistance of RHA-based steel fibre reinforced concrete is relatively restricted, as is understanding of concrete behaviour in hostile chemical content environments. As a result, determining the chloride ingress resistance characteristics of RHA-based steel fibre reinforced concrete structures might offer important information regarding the lifetime of these structures. Research into chloride migration resistance is of interest since the findings may be utilized to build reinforced concrete structures with a longer life. Many researchers investigated the replacement of OPC in concrete with rice husk ash (Chrismaningwang *et al.*, 2017), bagasse ash (Mahima *et al*., 2017), fly ash (Simi *et al*., 2015; Uthaman *et al*., 2018) and palm oil fuel ash (Chindaprasirt *et al*., 2011; Mujah, 2016) and discovered that these pozzolanic materials could enhance the resistance of chloride migration in concrete.

Chloride-induced corrosion of RC buildings is a concern in colder locations where concrete is frequently exposed to de-icing salt during the winter season. As a result, cracks in concrete buildings may form. While these fractures do not have a significant impact on the load bearing capability of the structures, they do have an unfavourable effect on their durability performance by allowing water and other hostile chemicals, such as chloride ions, to enter. Numerous studies have been done in recent decades to investigate the problem of chloride intrusion in fiber reinforced concrete. According to Avdar (2014) and Mastali *et al.* (2016), the combination of pozzolanic materials and PP fiber was shown to be an effective option for inhibiting the passage of aggressive particles through concrete. Furthermore, both Mohammadhosseini *et al*.

(2020) and Medina *et al.* (2014) discovered that chloride penetration and water absorption were considerably lower for waste metalized plastic fibre and PP fibre concrete composite.

Aside from concrete mechanical characteristics, factors of concrete durability such as chloride intrusion are heavily weighted in the evaluation of performance and potential use of any innovative waste material in concrete composites. To the best of the authors' knowledge, no literature exists on the chloride ingress resistance characteristics of RHA-based green concrete composites including steel fibre. Because of the pozzolanic behaviour of RHA and the availability of steel fibres, studies on the use of the components in concrete were conducted. As a result, the goal of this article is to use RHA as a supplementary cementing material (SCM) in steel fibre concrete composites to maximize the benefits of chloride migration resistance, strength, and air pollution reduction by reducing massive OPC production that generates cement kiln dust, a by-product formed during the cement manufacturing process. As a result, negative environmental consequences connected with the procurement and processing of Portland cement raw materials are avoided.

This experiment with RHA in steel fibre reinforced concrete composites could be environmentally friendly as well as economically beneficial because it reduces landfilling issues and reduces the use of virgin and natural resources, thereby contributing to overall cleaner production in the construction industry.

MATERIALS AND METHODS

Materials Selection

This study made use of Dangote Portland cement (CEM 1) 42.5 N grade. The cement used satisfies the ASTM C150 standards (2016). Furthermore, the fine aggregate (4.75 mm maximum size) utilized in the concrete mixture was acquired from a river near Gidan - Kwano village in Minna, Niger state. The river sand has values of 1690 kg/m^3, 1.87 percent, 2.61, and 2.4, respectively. Crushed granite with a relative specific gravity of 2.81, a bulk density of 1525 kg/m^3, 1.80 percent water absorption, and a maximum size of 10 mm was utilized as the coarse aggregate.

The rice husk used in this recipe was obtained from a rice mill waste dump in Zungeru, Niger state. It was subsequently burned at temperatures ranging from 500 to 700 degrees Celsius in a locally constructed incinerator, as shown in Figure 1. The resulting grey ash was sieved with a 1.18mm sieve to eliminate any impurities from the burning before being ground to a particle size of 75um and a 15 percent replacement by weight of cement was employed for the investigation. The chemical characteristics of RHA were analysed using X-ray fluorescence (XRF), and the results are shown in Table 1. The total of the three primary oxide values (Fe_2O_3 + SiO_2 + AI_2O_3) is 85.71, which is in compliance with ASTM 618 (2015), which stipulates that (Fe_2O_3 + SiO_2 + AI_2O_3) shall not be less than 70%.

Figure 1: RHA Production Process

Table 1: Chemical Properties of RHA

`Oxides	% Composition
Fe_2O_3	1.38
SiO_2	83.79%
AI_2O_3	0.54
CaO	1.26
MgO	1.55
Na_2O	___
K_2O	1.56
P_2O_5	6.29
TiO_2	0.20
SO_3	___
L.O.I*	2.93
% of Important Oxides (Fe_20_3+$Si0_2$+AI_20_3)	85.71

Also, potable tap water from bore hole in FUT Minna campus was used to prepare all concrete mixtures including curing. A water reducing admixtures was used in other to achieve the target slump. Super plasticizer (SP) of trade name Conplast SP400 conforming to ASTM C494/C494M (2016) requirement was used to improve the workability of the fresh concrete. Due to high viscosity, appropriate percentage Super plasticizer (SP) was dissolved as part of mixing water before being added to the concrete mixtures.

The steel fibre used in this research is Galvanized smooth straight binding steel wire (Density of 7850kg/m^3). The binding steel wire is usually used in concrete structures as a binder to reinforcement links and reinforcement bars. Preliminary test was carried out on it and it was confirmed suitable for use. The properties of the steel fibre used in this study are as offered in Table 2. The fibre diameter was measured to be 1 mm using Vernier calliper and the fibre was cut into 30 mm length referring to the best performing length from the preliminary study were effect of varying fibre length were studied (Figure 2). Steel Fibre Reinforced Concrete (SFRC) specimens were prepared with addition of 0%, 0.5%, 1%, 1.5% and 2% steel fibre (SF) by volume of concrete. This range of fibre volume fractions was selected based on the existing literature as well as a series of experimental works before the main work. However, the addition of fibres beyond 2% negatively affects the performance of concrete. These specimens were prepared to investigate the properties of SFRC in different contents after curing period of 7, 28, and 56 days.

Figure 2: Galvanized steel wire (GSW)

Table 2: General properties of fibres

Properties	**Value**
Length (mm)	30
Diameter (mm)	1.0
Length/diameter	30
Density (kg/m^3)	7850
Tensile strength (N/mm^2)	1100
Modulus of elasticity (N/mm^2)	200

Methods

Mix proportion and specimens preparation

The concrete mixture used in this experimental program was a mixture of crushed granite, natural sand and cement (CEM I 42.5 N). Concrete mixes were designed as a nominal mix to determine the influence of steel fibre as reinforced fibre to ordinary concrete with a water to cement ratio (W/C) of 0.48. The proportioning of concretes mix referred to ACI 211 (2019). The proportions of concrete mix design are presented in Table 3.

The cyphers (Mix ID) of concrete are consigned by the integration of English consonants and numbers which had the main type of concretes of CON and RHA, when CON is control concrete using CEM 1 as binder. RHA is a concrete produced by blending 15% RHA to the 75% CEM 1 Portland cement as a binder and 0, 1, 2, 3 and 4 are the varying fibre volume fraction at 0%, 0.5%, 1%, 1.5% and 2% respectively. For example, CON0 is the concrete made without substituting the CEM 1 with RHA pozzolan and steel fibre, thus serving as the control concrete. RHA1 is the concrete made by blending 15% RHA to CEM 1 as a substitute to serve as a binder with an inclusion of 0.5% steel fibre.

Table 3: Mix design proportion for 1 m^3 of concrete

Mix ID	Cement (Kg/m^3)	RHA (%)	RHA (Kg/m^3)	(V_f) (%)	(V_f) (Kg/m^3)	Sand (Kg/m^3)	Crushed Granite (Kg/m^3)	Water (Kg/m^3)	SP (%)	W/B Ratio
CON0	521	0	0	0	0	748.5	748.5	250	0.2	0.48
CON1	521	0	0	0.5	49.25	748.5	748.5	250	0.4	0.48
CON2	521	0	0	1.0	98.50	748.5	748.5	250	0.4	0.48
CON3	521	0	0	1.5	147.75	748.5	748.5	250	0.4	0.48
CON4	521	0	0	2.0	197.00	748.5	748.5	250	0.4	0.48
RHA0	442.85	15	78.15	0	0	748.5	748.5	250	0.5	0.48
RHA1	442.85	15	78.15	0.5	49.25	748.5	748.5	250	0.7	0.48
RHA2	442.85	15	78.15	1.0	98.50	748.5	748.5	250	0.7	0.48
RHA3	442.85	15	78.15	1.5	147.75	748.5	748.5	250	0.7	0.48
RHA4	442.85	15	78.15	2.0	197.00	748.5	748.5	250	0.7	0.48

Preparation of aggressive medium

To assess the depth of chloride penetration of the RHA based SFRC, cylindrical specimens comparable to the tensile strength test of 100 x 200 mm were prepared and tested. After casting, the concrete specimens were then cured in water for 28 days. Once the curing period is done, three-cylinder samples from each batch were immersed in a 5% sodium chloride (NaCl) solution. The exposure periods were designed for 7, 28, and 90 days. Three samples were prepared for each concrete batch at the end of exposure time and split the cylindrical specimens into two parts along the length. Then, the freshly exposed faces of the specimens were sprayed with 0.1 N silver nitrate ($AgNO_3$) solution to see the penetration depth. As shown in Figure 3, directly after spraying the $AgNO_3$ solution, the outer portions of the samples were brighter owed to the silvery deposit of silver chloride (AgCl), which indicates the penetration depth of chloride ingress, although the internal portions were darker, owing to the existence and consequence of silver hydroxide (AgOH).

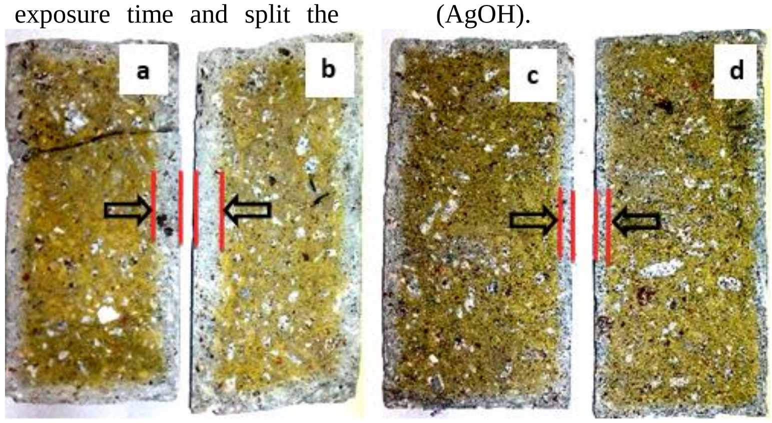

Figure 3: The depth of chloride penetration indicated by $AgNO_3$ solution for (a) CON0 (b) CON2; (c) RHA0, (d) RHA2 concrete mixes

Specimens testing procedure

Concrete mixes were examined for the slump test according to ASTM C 143 (2018) and VeBe time test following BS EN 12350-3 (2018). To evaluate the cube compressive strength, cubic samples of size 100 mm were prepared, cast, and tested following BS EN 12390-3 (2019) recommendations. Cylindrical specimens piloted the tensile strength with a dimension of 100 mm x 200 mm based on the ASTM C496 (2019).

RESULTS AND DISCUSSION

Fresh Properties

The experimental results of the fresh density of the various mixes are shown in Figure 4a. It was observed that the fresh density increases with rising fibre dosage. This was predictable owing to the high density of the steel fibres, which is approximately about 7850kg/m^3 associated with that of conventional concrete. The inclusion of RHA into the mixtures however lead to reduced density of the blended concrete than that of OPC-based mixtures. This phenomenon could be because of the lesser relative density of RHA related to that of CEM 1. As illustrated in Figure 4a, amongst all the mix, the highest fresh density value was noted for the CEM 1 mix with 2% fibres.

The fresh concrete mixes made of RHA based steel fibre reinforced concrete, was tested for workability using the slump and the VeBe time test. The outcomes of the workability tests are demonstrated in Figure 4(b and c). It can be observed that the workability of concrete mixes considerably reduced by the inclusion of steel fibres. From Figure 4b, the slump of the plain concrete mix without any fibre and RHA was measured as 165 mm. With the inclusion of steel fibres by 0.5%, 1.0%, 1.5% and 2.0%, the slump values dropped to 150, 135, 110 and 80 mm, correspondingly. Moreover, due to the higher surface area of RHA than CEM 1 (42.5N), the matrix absorbs more quantity of water and consequently, making the mixture stiffer and resulted in lower workability leading to balling effect of the concrete mix at 1.5% and 2% of fibre content. The behaviour of the mix agrees with the report of Mohammadhosseini *et al*. (2020). From the results given in Figure 4b, it can be observed that in mixes with 15% RHA, the slump dropped to 110 mm, and the VeBe time raised up to 4 sec as likened to that of 165 mm and 3 sec for CEM 1 plain concrete. A similar tendency like that of CEM 1 mixes was observed for RHA mixes reinforced with steel fibres.

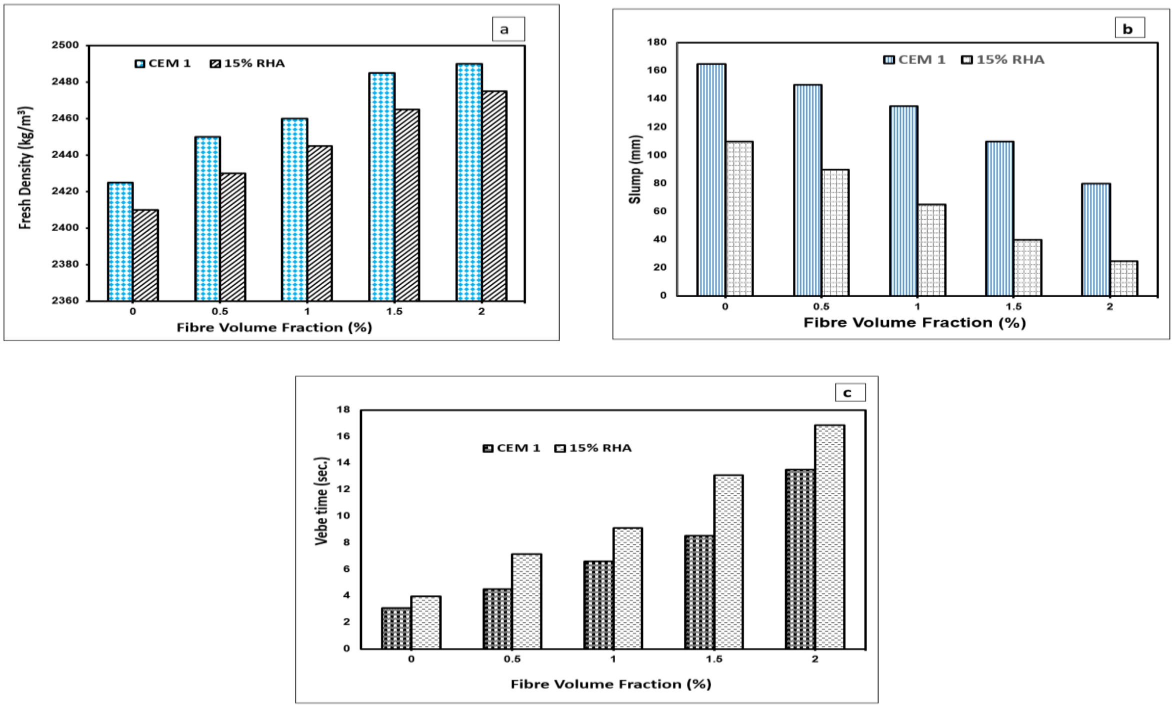

Figure 4: Influences of steel fibres on (a) fresh density (b) slump (c) VeBe time and of fresh concrete mixtures

Compressive Strength

The achieved compressive strength of the tested concrete specimens is illustrated in Table 4. The results show that the inclusion of steel fibres slightly increase the compressive strength of the concrete. The inclusion of steel fibres at the volume fractions of 0.5%, 1.0%, 1.5%, and 2.0%, resulted to increase in the 7-day compressive strength of CEM 1-based concrete specimens by 6.32%, 13.44%, 12.09%, and 11.49%, respectively. Though, after 56-day curing in water, RHA based fibre reinforced concrete mixes attained higher compressive strengths than that of CEM 1 fibre reinforced concrete mixes. At the age of 56 day, the compressive strength values of RHA based concrete mixes increased by 17.60%, 27.91%, 22.36%, and 21.14%, correspondingly. It is observed that at the longer curing periods, the existence of RHA influenced the enhanced performance of concrete strength achieved. The pozzolanic characteristics of RHA in conjunction with the supplementary C-S-H gel during the hydration process strength development lead to the enhanced performance of the concrete compressive strength (Mohammadhosseini *et al.*, 2020).

Table 4: Strength test values of concrete

Mix ID	RHA (%)	(V_f) (%)	Compressive Strength (N/mm^2)			Tensile Strength (N/mm^2)		
			7 days	28 days	56 days	7 days	28 days	56 days
CON0		0	25.15	33.12	42.67	1.24	2.83	3.73
CON1		0.5	26.74	34.28	44.45	2.81	5.22	7.88
CON2		1.0	28.53	36.33	47.13	3.11	6.35	9.83
CON3	0	1.5	28.19	35.44	46.36	3.18	7.76	10.19
CON4		2.0	28.04	34.32	44.73	3.55	8.43	11.15
RHA0		0	23.65	31.84	48.33	3.31	6.87	10.38
RHA1		0.5	24.49	32.61	50.18	3.38	7.50	10.65
RHA2		1	25.32	34.75	54.58	3.57	8.94	11.24
RHA3	15	1.5	24.00	33.18	52.21	3.82	10.33	12.36
RHA4		2.0	23.36	31.97	51.69	4.27	10.73	12.99

Splitting Tensile Strength

The attained outcomes of the tensile strength test on concrete specimens containing steel fibres are also displayed in Table 4. In the inclusion of the steel fibres and subsequently increasing the fibre volume fraction, the tensile strength of the concrete is observed to considerably develop the concrete tensile strength when compared with the control concrete mix. The mixture of steel fibres and RHA resulted in the improvement of tensile strength. At the hydration period of 56 days, reinforcement of CEM 1 concrete mixes with steel fibres at the volume fractions of 0.5%, 1.0%, 1.5%, and 2.0%, give rise to enhanced tensile strength values by 111.26%, 163.54%, 173.19% and 198.93%, respectively, as compared to that of control mix without any fibres and RHA.

Although, for the RHA based mixtures at the curing period of 56 days and the equivalent fibre prescribed volume fraction, the tensile strength increased by 178.24%, 185.52%, 201.34%, 231.37%, and 248.26%, as associated to that of plain concrete control mix (without fibre but contain RHA). When the splitting occurred and was sustained, fibres bridging the split parts of the specimens acted over the stress transfer from the matrix to the fibres and, therefore, gradually supported the full tensile stress. Steel fibres increased the resistance of concrete specimens against the indirect tension and enhanced the strain capacity of the concrete and then, consequences in higher values of the tensile strength (Söylev & Özturan, 2014). The development in the tensile strength of concrete containing steel fibres up to 1.0% might be owed to the larger interaction surface area among fibres and the cement paste. However, further increases in fibre content beyond 1.0% resulted in lower tensile strength of concrete. This phenomenon could be owing to the increase in the matrix porosity with low workability at a high fibre content in addition to non-uniform fibres distribution (Mohammadhosseini *et al.,* 2020). The inter-particle friction amongst fibres and between fibres and aggregates also affects the orientation and distribution of the fibres and, therefore, the strength properties of the concrete composite. The increase in porosity may be linked to the development of micro-cracks and weak fibre-matrix bonding.

Chloride Diffusion

In this study, the chloride diffusion depth was examined by immersion of concrete specimens in 5% sodium chloride solution, and the results are illustrated in Figure 5. The inclusion of steel fibres in concrete also with RHA conveyed a grid structure in the matrix, which has a significant influence on reducing the chloride penetration into concrete as well as a decrease in the creation of cracks (Söylev & Özturan, 2014; De Weerdt *et al*. 2014). The outcomes of the test revealed that the depth of penetration in those mixes reinforced with steel fibres at a fibre content of 0.5%, 1.0%, 1.5% and 2.0% was noticeably reduced. At the age of 56 days, the depth of chloride penetration of 15.2 mm was found for the CEM 1 based mixture reinforced with 2% steel fibre, which is higher than that of the obtained value of 12.4 mm for control concrete mix without any fibres. Besides, lesser penetration depths were recorded for RHA based mixes at the same curing periods. For example, for RHA based mix containing 1.0% steel fibres, the chloride penetration depth was recorded as 5.50 mm, which is about 23.61% lower than that of the measured value for the control RHA mix without any fibres. However, a further increase in fibre volume fraction increased the permeability of concrete and, therefore, increased the depth of penetration.

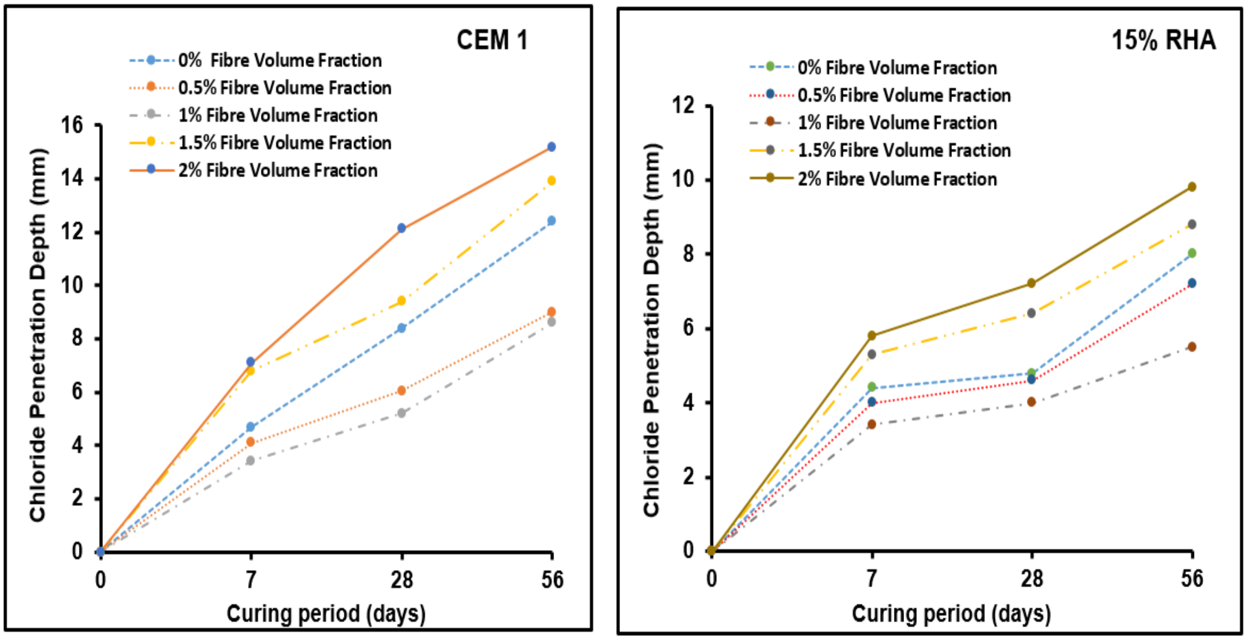

Figure 5: Influence of steel fibres on the chloride penetration depth of CEM 1 and RHA concrete

By comparing the depth of chloride penetration given in Figure 5, it can be observed that the combination of RHA and fibres into the concrete caused a breakdown of more significant voids in the matrix and, therefore, filled up the cavities through the formation of additional hydration products. It is owing to the finer particle size of RHA as compared to that of CEM 1 particles in addition to the high pozzolanic activity of RHA. During the pozzolanic reaction of RHA, a substantial amount of calcium hydroxide ($Ca(OH)_2$) involved in the pozzolanic reaction and react with active SiO_2 of RHA results in the formation of extra C-S-H gel (Chandara *et al*., 2010). This additional hydration produces, therefore, provides a dense microstructure in the concrete matrix and reduces the amount of porosity and, consequently, lower depth of chloride penetration.

CONCLUSION

The study looked at chloride penetration and strength of durable concrete. The usage of RHA and steel fibres contributed to the conservation and sustainable production of green concrete through the reuse of farm waste (RHA). Approximately 24% decreased the depth of the penetration of chloride in concrete samples with 1.0% stainless steel and 15% RHA. The production of durable concrete is extremely achievable, both in structural and non-structural applications, thanks to the inclusion of stainless steel and RHA fibre. The RHA component of the FRC is 15% and is ideal for resistive intake of chloride. Therefore, RHA-based SFRC is suggested for use in a probable chloride-prone environment.

References

Altun, F, Haktanır, T & Arı, K. (2007). Effects of steel fibre addition on mechanical properties of concrete and RC beams. *Construction Building and Materials*, 21(1), 654–661.

Argiz, C., Moragues, A. & Menéndez, E. (2018). Use of ground coal bottom ash as cement constituent in concretes exposed to chloride environments. *Journal of Cleaner Production*, kk170, 25-33.

ASTM C 143. (2018). *Standard test method for slump of hydraulic-cement*. Philadelphia, U.S.A.: American Standards of Testing Material

ASTM-C496. (2018). *Splitting tensile strength of cylindrical concrete*. Philadelphia, U.S.A.: American Standards of Testing Material

ASTM C 618 (2015). *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. Philadelphia, U.S.A.: American Standards of Testing Material

Atis, C.D., & Karahan O. (2009). Properties of steel fibre reinforced fly ash concrete. *Construction Building Material*, 23(1) 392–399.

British Standard Institution (2018). BS EN 12350-3: *Testing fresh concrete. Vebe test*. 389 Cheswick High Road, London: British Standards Institution

British Standard Institution (2019). BS EN 12390-3: *Testing hardened concrete. Compressive strength of test specimens*. 389 Cheswick High Road, London: British Standards Institution.

Buratti, N., Ferracuti, B. & Savoia M. (2013). Concrete crack reduction in tunnel linings by steel fibre-reinforced concretes. *Construction and Building Materials*, 44(1), 249-259.

Çavdar, A. (2014). Investigation of freeze–thaw effects on mechanical properties of fibre reinforced cement mortars. *Composites Part B: Engineering*, 58, 463-472.

Chindaprasirt, P., Chotetanorm, C. & Rukzon, S. (2011). Use of palm oil fuel ash to improve chloride and corrosion resistance of high-strength and high-workability concrete. *Journal of Materials in Civil Engineering*, 23(4), 499-503.

Chindaprasirt, P., Chotithanorm, C., Cao, H. T. & Sirivivatnanon, V. (2007). Influence of fly ash fineness on the chloride penetration of concrete. *Construction and Building Materials*, 21(2), 356-361.

Chrismaningwang, G., Basuki, A. & Sambowo, K. A. (2017). The effect of seawater curing on the correlation between split tensile strength and modulus of rupture in high-strength concrete incorporating rice husk ash. *Procedia engineering*, 171, 774-780.

Datis Export Group (2020, September 03). Worldwide Cement Production from 2015 to 2019. Datis Export Group (datis-inc.com). https://datisinc.com/blog/2020/09/03/worldwide- cement-production-from-2015-to-2019.

De Weerdt, K., Orsáková, D. & Geiker, M.R., 2014. The impact of sulphate and magnesium on chloride binding in Portland cement paste. *Cement and Concrete Research*. 65, 30-40.

Elbaz, A. A., Aboulfotoh, A. M., Dohdoh, A. M., & Wahba, A. M. (2019). Review of beneficial uses of kiln dust (CKD), fly ash (FA) and their mixture. *Journal of Materials and Environmental Sciences*, 10(11), 1062-1073.

Falkner, H. & Henke, V. (1998). Application of steel fibre concrete for underwater concrete slabs. *Cement and Concrete Composite*, 20(1), 377–385.

Fapohunda, C., Akinbile, B. & Shittu, A. (2017). Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement–A review**.** *International Journal of Sustainable Built Environment***,** 6(2), 675-692.

Gutierrez, R.M., Diaz, L.N. & Delvasto, S. (2005). Effect of pozzolans on the performance of fibre-reinforced mortars. *Cement and Concrete Composite*, 27(1), 593–598.

Hamada, H. M., Jokhio, G. A., Yahaya, F. M., Humada, A. M. & Gul, Y. (2018). The present state of the use of palm oil fuel ash (POFA) in concrete. *Construction and Building Materials*, 175, 26-40.

Hsu, S., Chi, M. & Huang, R. (2018). Effect of fineness and replacement ratio of ground fly ash on properties of blended cement mortar. *Construction and Building Materials*, 176, 250-258.

Kayali O. (2004). Effect of high-volume fly ash on mechanical properties of fibre reinforced concrete. *Materials and Structure,* 37(1), 318–327.

Khongpermgoson, P., Abdulmatin, A., Tangchirapat, W. & Jaturapitakkul, C. (2019). Evaluation of compressive strength and resistance of chloride ingress of concrete using a novel binder from ground coal bottom ash and ground calcium carbide residue. *Construction and Building Materials*, 214, 631-640.

Koksal, F., Altun, F., Yig˘it, I. & Sahin, Y. (2008). Combined effect of silica fume and steel fibre on the mechanical properties of high strength concretes. *Construction Building Materials*, 22 (1), 1874-1880.

Lanzerstorfer, C. (2018). Fly ash from coal combustion: Dependence of the concentration of various elements on the particle size. *Fuel*, 228, 263-271.

Mahima, S., Bahurudeen, A., Santhanam, M., & Jayachandran, K. (2017). Service Life Prediction of Bagasse ash Blended Concrete in Marine Splash Zone. *Materials Today: Proceedings*, 4(9), 9664-9672.

Mandhkan, M., Azizkhani, R., & Harchegani, M. E. T. (2012). Effects of pozzolans together with steel and polypropylene fibres on mechanical properties of RCC pavements. *Construction and Building Materials*, 26(1), 102-112.

Mastali, M., & Dalvand, A. (2016). The impact resistance and mechanical properties of self-compacting concrete reinforced with recycled CFRP pieces. *Composites Part B: Engineering*, 92, 360-376.

Medina, N.F., Barluenga, G., & Hernández-Olivares, F. (2014). Enhancement of durability of concrete composites containing natural pozzolans blended cement through the use of Polypropylene fibres. *Composites Part B: Engineering*, 61, 214-221.

Mohammadhosseini, H., Lim, N. H. A. S., Tahir, M. M., Alyousef, R., Alabduljabbar, H., & Samadi, M. (2019). Enhanced performance of green mortar comprising high volume of ceramic waste in aggressive environments. *Construction and Building Materials, 212,* 607-617.

Mohammadhosseini, H., Alyousef, R., Lim, N. H. A. S., Tahir, M. M., Alabduljabbar, H., Mohamed,

A. M., & Samadi, M. (2020). Waste metalized film food packaging as low cost and eco-friendly fibrous materials in the production of sustainable and green concrete composites. *Journal of Cleaner Production*, 258, 120726.

Moffatt, E. G., Thomas, M. D., & Fahim, A. (2017). Performance of high-volume fly ash concrete in marine environment. *Cement and Concrete Research*, 102, 127-135.

Mujah, D. (2016). Compressive strength and chloride resistance of grout containing ground palm oil fuel ash. *Journal of Cleaner Production*, 112, 712-722.

Ogunbode, E.B. & Akanmu, W.P. (2012). Turning waste to wealth: Potential of laterized concrete using cassava peels ash (CPA) blended cement. *International Journal of Engineering Research & Technology (IJERT)*, 1(3).

Simčič, T., Pejovnik, S., De Schutter, G., & Bosiljkov, V. B. (2015). Chloride ion penetration into fly ash modified concrete during wetting–drying cycles. *Construction and Building Materials*, 93, 1216- 1223.

Sivakumar, A, & Santhanam M. (2007). Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibres. *Cement Concrete Composite*, 299(1), 603-608.

Song, P.S., & Hwang, S. (2004). Mechanical properties of high-strength steel fibre reinforced concrete. *Construction and Building Materials*, 18(1), 669–673.

Soutsos, M. N., Le, T. T. & Lampropoulos, A. P. (2012). Flexural performance of fibre reinforced concrete made with steel and synthetic fibre. *Construction and Building Materials*, 36(1), 704-710.

Soylev, T.A., Ozturan, T. (2014). Durability, physical and mechanical properties of fibre-reinforced concretes at low-volume fraction. *Construction and Building Materials*, 73(1), 67-75.

Sravanthi, I., & Ismail, M. (2016). Effect of Replacement of Fly ash and Rice husk Ash on Strength Studies of M25 Grade Concrete. *International Journal of Engineering Sciences & Research Technology*. 5(11), 438-446.

Sun, W., Chen, H, Luo, X. & Qian, H. (2001). The effect of hybrid fibres and expansive agent on the shrinkage and permeability of high-performance concrete. *Cement and Concrete Research*, 31(1), 595–601.

Thomas J, Ramaswamy A. (2007). Mechanical properties of steel-fibre reinforced concrete. *Journal Material Civil Engineering*, 19(1), 385–392.

Uthaman, S., Vishwakarma, V., George, R. P., Ramachandran, D., Kumari, K., Preetha, R., & Amarendra, G. (2018). Enhancement of strength and durability of fly ash concrete in seawater environments: synergistic effect of nanoparticles. *Construction and Building Materials*, 187, 448-459.

Yazıcı S., Inan G. & Tabak V. (2007). Effect of aspect ratio and volume fraction of steel fibre on the mechanical properties of SFRC. *Construction Building Material*, 21(1), 1250-1253.

Yazici, Ş. & Arel, H. Ş. (2012). Effects of fly ash fineness on the mechanical properties of concrete. *Sadhana*, 37(3), 389-403.

Zareei, S.A., 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 studies in construction materials*, 7, 73-81.