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Workability and Compressive Strength of Seawater-Mixed Concrete Containing Rice Husk Ash as Supplementary Cementitious Material

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Abstract: The world is grappling with the challenge of rapidly growing water crises. The increasing population demands increased infrastructure which at present leads to the consumption of trillion gallons of water every year in construction industry. This research aims to check the suitability of seawater as an alternate to freshwater for mixing and curing of concrete. Rice husk ash is used as supplementary cementing material in order to enhance the capacity of matrix to sustain higher stress. Specimens were prepared with rice husk ash using fresh water and seawater. Half of the specimens were cured in seawater and remaining half with freshwater. The water-cement ratio in this study was kept constant equal to 0.39. Workability of concrete was determined for both fresh water and sea water mixes. Density and strength parameters were determined at the end of curing periods. The workability of concrete was found to decrease in seawater compared to freshwater mixes. With the addition of RHA it was found to decrease in both freshwater as well as in seawater. The density showed a declining path with the use of seawater and increasing amount of RHA. The specimens for determining compressive strength were tested at 7 and 28 days. The compressive strength results concluded that initially rate of gaining strength of seawater specimen was higher than its freshwater counterpart. The seawater specimen showed higher strength at 10% replacement of cement with rice husk ash at the end curing period. It can be concluded that seawater added with RHA is suitable alternative to fresh water in concrete.

Keywords: Compressive strength, cement replacement, seawater, rice husk ash, concrete

1. Introduction

Water is a significant component in concrete, it is not only involved in the cement hydration but also it contributes to the workability of fresh concrete [1]. Therefore, the quality of water is very important, to obtain the desired properties of concrete including workability, strength and durability. The growing demand for river water due to global growth in population and industrialization has led to a higher depletion of freshwater resources, with subsequent per capita reductions in the freshwater available [2]. Additionally, the scarcity of freshwater is possibly becoming the most

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serious environmental problem in many countries. Earth contains only 2.5% of freshwater and most of it is frozen in glaciers and ice caps. The liberated freshwater is mainly found below ground, with only a small fraction present above it [3].

The recent report of the United Nations about natural resources published on 19th March 2018 is an indication of a critical situation of available fresh water around the globe [4]. It has been estimated that in 2050, more than half of the world's population will be suffering from water shortage problems even for drinking mainly in developing countries. Increasing population and development in infrastructure also need clean water. On the other hand, the concrete industry is estimated to use more than one trillion gallons of water every year excluding water demand for curing and washing. Thus, it is essential to conduct research for the substitution of fresh water. United Nations in its World Water development report proposed nature-based solutions (NBS) for water. NBS or mimic the natural process to enhance water availability and reduce threats associated with water-related disasters and climate change. It further says due to grey growth the huge potential for NBS remains under-utilized. It incorporates green infrastructure that can substitute, supplement or work alongside grey infrastructure in a cost-effective way [4].

According to code necessities, only freshwater can be taken into consideration for the preparation of concrete. Aitcin in 2000 reported that normally, at about 250 kg of cement for each $1m^3$ of concrete and a 0.5 w/c ratio, roughly 800 billion litres of water was utilized as a part of the concrete production during 1997. This quantity was further estimated to reach up to 825 billion litres in the year 2010 by Tony & Jenn in 2008. Further, utilization of freshwater for industrial purposes increases in proportion to a country's GDP. From 10% to 59% in low-income to high-income countries [5]. Therefore, it is indispensable to find an alternate source of water for the construction industry.

The earth contains 97% of seawater, this can be a suitable alternative to fresh water if its use permitted. Research is being carried out around the world to replace freshwater with seawater in the construction industry but still, there is no clear data available about its use. Hence this research is carried out to elaborate the use of seawater as 100% replacement of freshwater added with supplementary materials.

Since that seawater contains sulphate and is expected to attack concrete but because of the presence of chlorides, its attack usually does not become the cause of the expansion of concrete. The explanation lies in the fact that gypsum (calcium sulfate) and ettringite (calcium sulfoaluminate) are more soluble in a chloride solution than in water, which implies they can be more effectively drained out in seawater. In result, there is no interruption yet just a slow increment in porosity and reduction in strength.

Rice husk is an agricultural by-product which is obtained in most parts of the world especially in Malaysia, Thailand, India and Pakistan. It is obtained from the milling of paddy. As a rough estimate five million tons of rice husk is produced throughout the world every year. Mostly it is used as fuel in power plants or in boilers of various industrial sectors to produce steam. The deposit received thereafter contain approximately 90% of silica by mass, which is of low reactivity and varies in colour from white to black. This poor reactivity limits the extensive use of this material. However, production of these by-products and residues are increasing every year. Therefore, there lies a great concern to incorporate these solid wastes into the construction industry. The rice husk ash (RHA) possesses good pozzolanic properties because of its high silica content. Properties and characteristics of the RHA are acutely connected with parent material and the methods adopted for its production. Investigations indicated that RHA has high pozzolanic properties because of its amorphous nature, fineness and high specific surface area [6][7][8][9]. It was also observed by that pozzolanic properties largely depends upon the amorphousness of RHA

2. An Overview of Seawater and RHA in Concrete

There are some areas in the world where seawater is being utilized for the preparation of concrete as well as for its curing with or without intention [10]. The discussion on seawater effects on concrete started in 1840, named "What is the trouble with concrete in seawater" [11]. It is also observed that concrete gets deteriorated because of the stresses resulting by crystallization of salts within the pores of the concrete [12]. Neville and Brooks recommended that seawater should be prohibited if it is to be used for reinforced concrete [13]. However, in a research carried out in Japan by Port and Airport Research Institute, it was observed that chloride measured in concrete after 20 long years of exposure is not affected by seawater. The negative effect of seawater used in concrete decreases with age [14]. Yogitha reported about the suitability of seawater for the preparation of concrete. It was stated after a detailed investigation for 180 days, concrete made and cured with seawater shows compressive strength loss of about 10% compared to freshwater [15].

In another study, test results indicated that seawater produces concrete of slightly higher initial strength but decreased long-term strength, the loss of strength is usually not more than 15% [16]. This loss of strength can be copped up by decreasing water to binder ratio [17]. O. U. Orie and A. M. Ojaruega stated that concrete specimens cast and cured with seawater showed decreased compressive strength compared to one with normal water [18]. Similar results were observed by the [19]. Guo and his co-workers carried out the detailed experimental studies with different grades of concrete using seawater. In their study, 192 cubes were cast and cured in seawater to study the effect of seawater on compressive strength of concrete. They reported a 15% reduction in compressive strength of concrete prepared with seawater compared to its freshwater counterpart [20]. In another research 140 cubes were made using a water-cement ratio of 0.6. Seventy specimens were prepared and cured with seawater water while remaining with freshwater as reference specimens. The results of compressive strength showed that compressive strength is increasing at all ages up to 90 days [21]. A detailed study was carried out by [22] on the use of seawater in the preparation of concrete. The experimental studies consisted of compressive strength, tensile strength and bond strengths which indicated that seawater for concrete shows higher early strength but it decreases with time.

P. Krishnam Raju, V Lakshmi, and S Bhanu Pravallika (2014) determined the effect of using seawater on the flexural and compressive strength of concrete. The experimental studies consisted of 54 cubes, 54 cylinders and 54 beams inclusive of reference specimens for 7, 28 and 90 days of curing. Their investigations revealed that there was no significant reduction in the strength when seawater was used for mixing and curing of concrete[23][23][23][23]. Similar results were reported by [22][21] [20]. The antagonistic impacts of seawater on concrete is for the most part a direct result of magnesium sulfate ($MgSo_4$) present in it, which is intensified by the presence of chloride which delays the swelling that generally portrays the assault by sulfate in seawater which results whitish in appearance, where the more severe attack drives it to spall and crack. At last, it is diminished to soft mud. Initially, the strength of concrete is found to increase whereas, it decreases later. It is additionally asserted that potassium and magnesium sulfate available in seawater reacts promptly with calcium hydroxide $Ca(OH)_2$ available after hydration of cement. The more severe attack is observed by magnesium sulphate ($MgSO_4$) which forms the sparing soluble magnesium hydroxide that pushes the reaction to form gypsum. $MgSO_4$ will react with calcium aluminate hydrate to form calcium aluminium sulphate hydrate (ettringite). It may also react with calcium hydroxide to form calcium sulphate which reacts with calcium aluminate hydrate to form ettringite salts. There also lies a tendency that Magnesium sulphate reacts with calcium silicate hydrate gel to form calcium sulphate, magnesium hydroxide and silica gel. The magnesium hydroxide formed reacts with silica gel to form magnesium silicate hydrate a soft white material found in deteriorated concrete [24]. Akshat Dimri reported the work of Mori who said there is not much difference between the strength of concrete either mixed with freshwater or seawater. He concluded that this difference of strength was observed very small after 10 years of experimental study [25]. Deterioration is not only because of chloride available from seawater but it is also because of exposure to the aggressive environment, mainly sulphate attack. However, the water-cement ratio of concrete being of vital importance [26]. Proper water to binder ratio such as 0.27 or less with proper admixture can be helpful [14].

When the rice husk ash is used as the supplementary cementing material the compressive strength is observed to increase. Fapohunda cited the work of Babaiefar (2007) who found this rise in strength up to 20% at w/c ratio 0.3, 0.32 and 0.35 for the curing periods of 7, 28 and 90 days [27]. Tuan *et al* in 2011 attributed this increased strength, to increased C-S-H compound, decreased porosity which resulted in dense concrete [28]. Similarly [29] also attributed the improved properties of RHA mixed concrete to the formation of C-S-H gel . The highest compressive strength was achieved at 10% replacement, afterwards, it started decreasing. The chloride resistance is increased substantially and is observed to be proportional with percentage replacement. Similar results were observed by [30]. It was also observed that RHA as the pozzolanic material provides decreased early strength and increased long-term strength which may be due to its delayed pozzolanic activity. To evaluate the effect of RHA on long-term properties of concrete, two different concretes were prepared. Concrete specimens were prepared with 5, 10, 15, 20 and 25% replacement of cement with RHA and compared with controlled specimens. The optimum content of RHA was observed as 20% thereby reduction in strength was observed [31].

In another experimental program [6] and [32] studied the effects of introducing rice husk ash in cement paste and concrete to study its influence on hydration and microstructure of interfacial transition zone between aggregates. Calcium hydroxide and calcium silicate hydrate were observed as major hydration and reaction products. The introduction of rice husk ash utilized $Ca(OH)_2$ content which left its leftover less than the control specimens. The utilization of rice husk ash in concrete decreased porosity which is supposed to be a reason for increased strength. The 10% replacement of cement with RHA showed the similar values of compressive strength as that of control concrete specimen. In another study, 200 specimens were cast and cured for 3,7, 28 and 150 days to study the effect of replacing cement partially with rice husk ash. The results indicated that optimum content of RHA is around 10% to 20% when finely ground. It was further observed that the rate of hydration of concrete containing RHA is slow, during the initial three days which also affects the results of 150 days [33]. M. Nehdi and his co-workers carried out their experimental programme using rice husk ash produced through controlled combustion and compared results with control and silica fume incorporated specimens. The compressive strength was found increasing and better reduction in chloride permeability was observed compared to both reference specimens [34] [6]. The increase in strength is attributed to the increased amount of C-S-H gel, similar results were observed by [32]. The 10% replacement of cement with rice husk ash showed strength improvement up to 30.8% and when this replacement increased up to 20% there was no adverse effect on the strength [35].

Properties and characteristics of the rice husk are acutely connected with parent material and the methods adopted for its production. Open field burning and controlled incineration are the two methods for its production. In controlled incineration method, both temperature and its duration are controlled. For the better quality of ash, a suitable incineration method and proper grinding should be adopted. The particle size of the RHA particle decreases with increasing grinding time and strongly influences the compressive strength of concrete [36]. Physical properties of RHA are very important as they can affect strength and durability characteristics including specific gravity, mean particle size and Blaine fineness. Various researchers led their research and demonstrated that specific gravity of RHA varies between 2.05-2.53, which is relatively lower than the specific gravity of cement which lies between 3.10-3.14 [37][17][38][39][40]. They further demonstrated that, when cement is replaced with RHA, relatively higher volume was produced which is due to fact that concrete made with RHA have lower density and this reduction further increases as the percentage of replacement increases. Similar results were observed by [41] and [42]. Many researchers are agreed on fact that RHA should be ground to very fine particles to obtain a very high specific surface area [40][43]. It was reported that the highest pozzolanic properties were achieved when RHA was ground to 7000 cm^2/kg [7]. Nehdi (2003) concluded that RHA having a particle size lower than 45 microns can aggressively take part in pozzolanic reaction [34].

3. Experimental Work

3.1 Preparation of Material

The seawater used in this study was obtained from a Sungai Lurus seaside near Batu Pahat, Johor, Malaysia (see Fig. 1). The observed pH of seawater is 8.2 and specific gravity is 1.024. In this study, concrete was prepared using 100% seawater instead of fresh water in the second main group and then immersed in seawater for curing.

The prepared RHA was used in a mixture at 10%, 15% and 20% by weight of OPC for specimen prepared with freshwater as well as seawater. Meanwhile, the rice husk was collected from local paddy located in Muar, Johor. In this experimental work, rice husk ash was produced under controlled conditions at a temperature of 650^0C. The period of incineration was kept constant up to 60 minutes as recommended in the study by [44]. Then, the incinerated RHA was ground in the loss-angles machine for three hours to decrease the particle size for improving the pozzolanic activity which then was used in the experimental study (see Fig. 2).

Other conventional materials are ordinary Portland cement (OPC), river sand and gravel. OPC conforming to BS EN 197-1:2011 has a specific gravity of 2.80. Natural river sand with a fineness modulus of 2.34, specific gravity of 2.55 and water absorption of 1.02% was used. Whereas the coarse aggregate has specific gravity 2.68 and water absorption of 0.95%.

Fig. 1 – Seawater collection.

(a) (b) (c)

Fig. 2 – The production method of rice husk ash, (a) rice husk, (b) the burning process of rice husk ash at 650^oC, (c) rice husk ash in room temperature.

3.2 Preparation of Material

The control mix with freshwater was designed as a conventional concrete to have a target compressive strength of 50MPa. The ratio of concrete mix proportion was 1:1.3:1.8; 1 part of cement, 1.3 parts of fine and 1.8 parts of coarse aggregate. The water-cement ratio was kept constant throughout this experimental study which was equal to 0.39 and a target slump of 60-180mm. The control and blended specimen were prepared using seawater and freshwater. Mixture description and mix design are shown in Table 1 and Table 2 respectively.

The mix was prepared to evaluate the workability and compressive strength of blended seawater-mixed concrete. Two main group of the mixture were designed and each main group consist of four mix series. The first main group consisted freshwater as mixing water and the second main group using seawater as mixing water. Total of 24 cubes including conventional concrete (Control A) were prepared for evaluating the compressive strength of concrete. All materials excluding admixture and water were dry mixed for three minutes. The water and admixture were mixed together and then added to the dry mix and mixing was continued for an additional 2 minutes. Slump value was measured according to BS EN12350-22009. Fresh mixture was then poured in the 100x100x100 mm cube mould. Freshwater mixed group specimen were placed in freshwater curing tank and seawater mixed group were immersed in seawater curing tank after demoulding. Compression test was conducted at age 7 and 28 days of hydration process. The compressive strength of cubes was measured according to BS EN12390-32009.

Table 1 – Description of the mixture

Mixture	Description
Control A	Conventional OPC mixed with 100% freshwater
FW-10RHA	100% freshwater + 90 % ordinary Portland Cement + 10% rice husk ash
FW-15RHA	100% freshwater + 85 % ordinary Portland Cement + 15% rice husk ash
FW-20RHA	100% freshwater + 80 % ordinary Portland Cement + 20% rice husk ash
Control B	Conventional OPC mixed with 100% seawater
SW-10RHA	100% seawater + 90 % ordinary Portland Cement + 10% rice husk ash
SW-15RHA	100% seawater + 85 % ordinary Portland Cement + 15% rice husk ash
SW-20RHA	100% seawater + 80 % ordinary Portland Cement + 20% rice husk ash

Table 2 – Mix proportion of concrete

Mixture Series		RHA/C (%)	w/c	Water W (kg/m³)	Cement C (kg/m³)	Rice Husk Ash RHA (kg/m³)	Sand S (kg/m³)	Coarse Aggregate CA (kg/m³)	Chemical Admixture (%)
Freshwater mixed	Control A	0	0.39	210	540	0	690	960	0.9
	FW-10RHA	10			486	54			1.0
	FW-15RHA	15			459	81			1.2
	FW-20RHA	20			432	108			1.3
Seawater mixed	Control B	0	0.39	215	552	0	110	960	1.5
	SW-10RHA	10			497	55			1.5
	SW-15RHA	15			469	83			1.6
	SW-20RHA	20			442	110			1.6

4. Results and Discussion

4.1 Workability and Hardened Density

Slump test was conducted right after mixing drum stopped (Fig.3). At w/c of 0.39, both control A and control B achieved 60 mm of slump value and this value was decreasing when RHA was added. The chemical admixture was used to improve the workability of the mixture. With the addition of admixture, the slump value was well achieved within target limits of 60-180 mm as shown in Fig. 4. The amount of chemical admixture was increasing with the increasing percentage of RHA. It was further noticed that for seawater mixed concrete, the dosage of chemical admixture required was slightly higher compared to freshwater mixed concrete.

Slump gives us a direct indication of workability and relative factor between the mixes when a fixed amount of water is used. With the common slump value and a fixed amount of water added for entire mixes. The parameter that becomes the deciding factor on workability is the amount of admixture used to achieve target slump. The physiochemical characteristics of ashes used are accountable for changes in the slump. Any RHA addition increased the chemical admixture demand or else the water requirement of concrete. This demand is proportional with the quantity of RHA used with the major increase recorded at maximum RHA used. Similar results were reported by other researchers [7].

The results of workability obtained in this research indicate that workability is decreasing with increasing amount of RHA which may be due to the particle size, surface area or irregular shape of RHA particles. It may also be due to the porous nature of RHA particles absorbing more water. A similar pattern of results was also observed by few other researchers [45]. The difference of workability was also observed between seawater and freshwater mixes. The results showed that for seawater workability is decreasing compared to freshwater which may be due to more amount of solids present in seawater. Also, the chloride ions present in seawater accelerates the setting of cement. In order to keep the value of the target slump constant, the chemical admixture was used in different dosages. The increased value of slump with 20% RHA is because of more amount of admixture in the mix.

The values of density of concrete were measured after 28 of curing. The observed results are shown in Fig. 5. The use of RHA decreased the values of density. The results indicated that the density of concrete is decreasing as the amount of RHA is increasing. This decrease in the values of hardened density can be attributed to the porous nature of RHA particles. It was further observed that the use of seawater decreases density.

Fig. 3 – Workability test

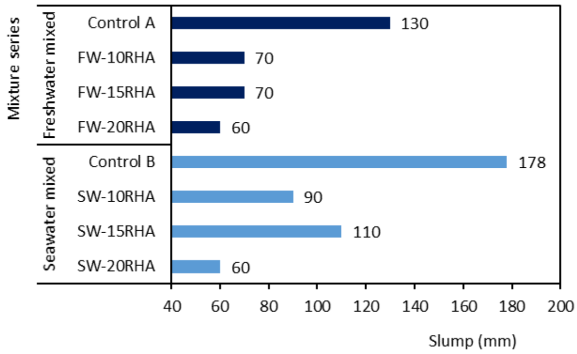

Fig. 4 – Slump of fresh concrete with freshwater and seawater mixed.

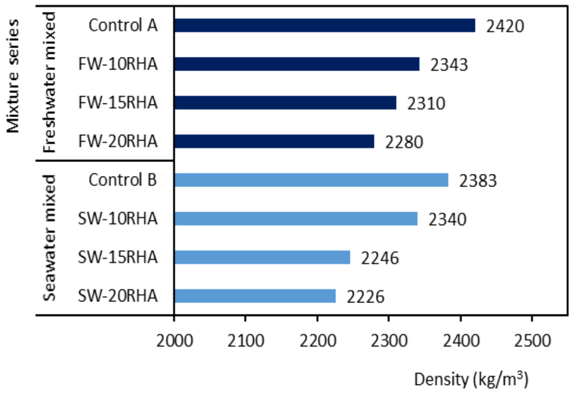

Fig. 5 – Hardened density of concrete at age 28 days

4.2 Development of Compressive Strength

It was observed at the end of this experimental program that seawater specimen showed higher early strength compared to their freshwater counterpart. Whereas in longterm the compressive strength results of seawater specimens were similar to the freshwater specimen. These results at early ages can be attributed to Cl_2 ion present in seawater which may have accelerated the hydration process to form CSH gel earlier. Over the examined period of time, the reference specimen exhibited strength superiority at all the ages in both mixes which may be due to the slow start of the pozzolanic reaction of RHA in the mix. It is generally observed that when RHA replaces the cement partially the early strength of concrete is decreased because of a slow start in pozzolanic reaction. After the first weak RHA specimen developed strength at the faster rate. At the testing age of 28 days, the 10% replacement of cement with RHA using seawater showed higher strength compared to its freshwater counterpart. The 15% RHA showed the same strength both in seawater specimen and freshwater specimens. The reduction in strength was observed with increasing amount of RHA. This may be due to fact that quantity of RHA available in the mix is higher than the required in the mix to combine with liberated lime during the hydration process which results in excess silica leaching out causing a reduction in strength as it replaces the part of cementitious material but does not contribute to strength. The compressive strength of the reference specimen using seawater after 28 days showed 3% reduction in strength compared to its freshwater counterpart. The observed changes in the values of compressive strength are shown in Fig. 6 and Fig. 7.

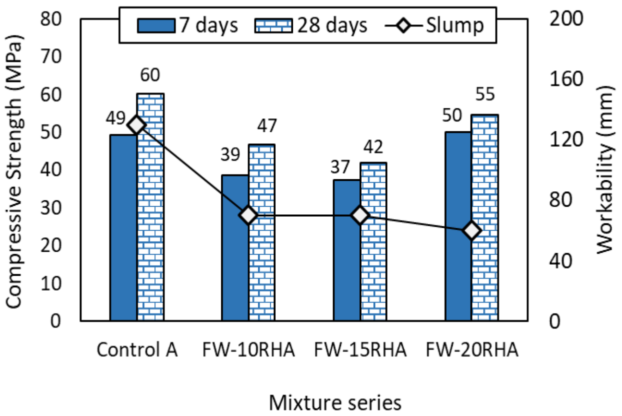

Fig. 6 – Development of concrete compressive strength at 7 and 28 days for mixing and curing using freshwater

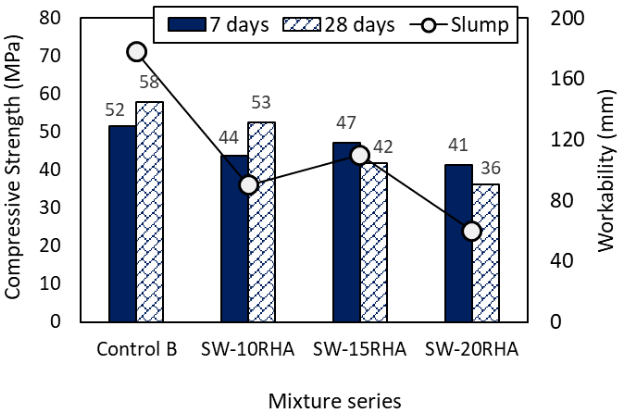

Fig. 7 – Development of concrete compressive strength at 7 and 28 days for mixing and curing using seawater

5. Summary

It is investigated from this experimental programe that the RHA can be a better replacement of cement when seawater is used as water for mixing and curing in concrete. The results of strength so observed using seawater are comparable to reference specimen prepared with fresh water. After performing this experimental work following conclusions can be drawn:

- Workability of reference specimens was found to decrease when seawater was used for mixing concrete. The use of rice husk ash further decreased slump value. The admixture was used in order to achieve the target slump value.
- The density of specimens with both the freshwater and seawater was found to decrease with increasing percentage of rice husk ash in the mix. The reduction in the density may be due to the porous nature of rice husk ash particles. The use of seawater also decreased the density of concrete.
- The use of seawater shows higher early strength but the rate of gaining strength decreases at the greater ages. The higher early strength of seawater specimen may be due to the presence of Cl_2 which acts as an accelerator and accelerates the hydration process. The early formation of CSH gel becomes the core reason for the early strength.
- The control specimen B after seven days showed higher strength compared to its freshwater counterpart but this pattern reversed later. The 10% and 15% replacements of cement with RHA showed higher strengths than their freshwater counterpart specimens. Results of using RHA showed positive effects when seawater is used for mixing and curing of concrete.
- This experimental investigation revealed that seawater specimens showed approximately similar strength as compared to those specimen which were made using freshwater. The rice husk ash has sufficient potential to

enhance the strength of specimens at longer ages hence It is further recommended to carry out a long-term investigation on the use of seawater with RHA.

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