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An Investigation on the Compressive Strength of Concrete with Rice Husk Ash as Cement Replacement and Addition of Chemical Admixtures

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Abstract

Rice husk ash (RHA) is a renewable agricultural by-product from rice milling that is abundantly available in rice-producing countries like the Philippines. It has the highest proportion of silica content among all plant residues. This study utilized RHA as a cement replacement with the addition of chemical admixture. An investigation of the influence of RHA and accelerating admixture on the compressive strength of concrete was conducted. A volumetric method concrete mix design was used with a 0.56 water-cement ratio. A 10% RHA partial cement replacement with chemical admixture variations of 0.5, 1.0, 1.5 and 2.0% was utilized. Cylindrical samples measuring 150 x 300 mm were tested for compressive strength at curing ages of 7, 14 and 28 days. The results of the study revealed that the optimum increase of compressive strength of 9.8% against the control concrete mix was achieved when a concrete mix of 10% RHA partial cement replacement was added with 1.5% of admixture. With a compression test result of 2,353 psi, the said mixture could be used for secondary applications such as flooring according to the American Concrete Institute M-15 code and for non-structural concrete such as concrete for sidewalks, borders and filling.

Keywords: chemical admixture, compressive strength, construction material, concrete, rice husk ash

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1. Introduction

With a land size of 30 million hectares, the Philippines is mostly an agricultural country. Agriculture accounts for 47% of the country's land area. Rice, coconut and sugarcane are key contributors to biomass energy resources among the crops farmed. Rice husk, rice straw, coconut husk, coconut shell and bagasse are the most frequent agricultural wastes in the country. Because rice is cultivated in one-third of the country's agricultural area, enormous volumes of rice straw and hulls are generated. Because of this, the country has a lot of potential for biomass power plants. Rice hull output in the Philippines is projected to be around 2 million tons per year, which equates to about 5 million barrels of oil equivalent (BOE) in terms of energy. According to Zafar (2021), rice straw can be an important biomass resource, which has a potential availability of more than 5 million tons per year across the country.

Rice husk is a significant by-product of the agro-based biomass sector and the milling of rice (Phonphuak and Chindaprasirt, 2015). A rice husk can be regarded as a biological silica ore because it contains 20% silica by weight. Husk makes up around 20% of paddy weight, and rice production in the Philippines produces two million metric tons of husk per year on average. Rice husks are sold for P1.80 per kg in the Philippines (Nidoy, 2016).

Only 5% of the yearly production of rice husk is used efficiently, primarily as a source of energy for cooking or as a soil additive. The remainder is either burned or left to deteriorate. Carbonized rice husk (CRH) is a useful product that may be made by partially burning rice husk in a carbonizer. Carbonized rice husk retains a lot of water, has a lot of air permeability, is very light, and is somewhat alkaline. Ash created by burning rice husks must also be utilized as a resource to recycle rice husks sustainably (Sekifuji and Tateda,2019). Others make use of rice husk ash, which is converted into biomass (Vinluan, 2002).

In concrete production, cement is an important ingredient. However, due to its high cost, rural communities in developing countries cannot afford it. One suitable material to partially replace cement is rice husk ash (RHA) (Muleya, 2021). In the study of Isberto *et al.* (2019), concrete containing up to 10% rice RHA replacement is optimal in maximizing the strength of cement mortar. Ramasamy (2012), Rahim *et al.* (2015), Habeeb and Hamud (2010) and Ephraim *et al.* (2012) have validated that the optimum percentage of RHA cement replacement is at 10%. Tuleun *et al.* (2019) conducted a study on the performance of concrete containing RHA and calcium carbide waste, and the results showed that maximum strength was attained at 10% replacement.

Modern concrete materials and processes are largely dependent on chemical admixtures. Chemical admixtures have also aided in the development of new concrete technologies, such as shotcreting, underwater concreting, self-leveling and concrete pumping. Therefore, it may be anticipated that chemical admixtures will continue to play a significant part in upcoming generations of concrete in the ongoing search for more affordable and ecologically friendly materials and technology (Spiratos and Jolicoeur, 2000). At present, no study has been conducted which introduces chemical admixtures to concrete mixtures with RHA as cement replacement. In this study, 10% RHA was used as cement replacement with variations of 0, 0.5, 1.0, 1.5 and 2.0% admixture to investigate the potential of these alternative materials in improving the concrete mix.

2. Methodology

2.1 Materials and Testing

The structural concrete produced in this study was in accordance with the minimum requirement for concrete structures stated in the National Structural Code of the Philippines (Association of Structural Engineers of the Philippines, 2015) and the Standard Specifications of the Department of Public Works and Highways (DPWH) (2017).

2.1.1 Cement

Type-1T Ternary blended cement was used in the concrete mixture. Type-1T cement is a special formulation of Portland cement with advanced mineral additives; this type of cement is commonly used for general construction. The testing included a loss on ignition (LOI) (American Society for Testing and Materials [ASTM] C114-18, 2018) and specific gravity (ASTM C188-17, 2017). Test results conducted by a DPWH Bureau of Research and Standards (DPWH-BRS) accredited laboratory in Cagayan de Oro City revealed that the LOI of the material was 2.43%, and the specific gravity was 2.80.

2.1.2 RHA

The RHA (Figure 1) was obtained from Oroquieta City, Misamis Occidental. To remove the organic components from the rice husk while keeping the silica amorphous and producing a highly reactive rice husk ash, a precise burning technique was employed. Amorphous silica would become crystalline at an excessive temperature, reducing its reactivity. In the literature, a 2-h burn time at 500 °C is advised (Pham, 2012). Only the material passing sieve no. 200 was used in the concrete mixture. Testing included LOI and specific gravity.

Test results conducted by a DPWH-BRS accredited laboratory revealed that the LOI and specific gravity were 6% and 2.72, respectively.

Figure 1. Rice husk ash

2.1.3 Fine and Coarse Aggregates

The fine and coarse aggregates were washed prior to use. The aggregates were quarried from the Tagoloan River, Tagoloan, Misamis Oriental. Both materials underwent testing such as sieve analysis (ASTM C136/C136M-19, 2019), unit weight (ASTM C29/C29M-97, 1997), specific gravity and water absorption (ASTM C127-15, 2015) according to ASTM C33-03 standard to ensure that it passed the standard quality requirements. Test results conducted by a DPWH-BRS-accredited laboratory revealed some of the physical properties of fine and coarse aggregates that were used in the design of the concrete mixture (Table 1).

Table 1. Physical properties of fine and coarse aggregates

Material	Unit weight (kg/cu.m)	Specific gravity (SSD)	Water absorption (%)	Fineness modulus
Fine aggregate	1,496	2.669	0.46	2.83
Coarse aggregate	1,384	2.641	1.47	-

2.1.4 Water

The water used in mixing was clean and free from alkaline, organic materials, or other harmful materials that can cause any deterioration to the sample. The appropriate amount of water in the concrete is crucial to the mix to lay the concrete in the desired position. The water-cement (W/C) ratio was appropriately followed to adhere to consistency requirements in preparing the concrete mix. The W/C ratio of 0.56 was obtained based on the standard design DPWH-BRS with all the test results of the materials as inputs.

2.1.5 Accelerating Chemical Admixture

The admixture used was JayconPlast NR, which is a chloride-free, high-range water-reducing admixture with an accelerating effect. It contains a sulfonated polymer and is specially formulated to impart rheoplastic qualities to concrete. This admixture was produced by R&J Trading and Services and mixed in El Salvador City, Misamis Oriental. The addition of admixture which varied by 0.5% and ranging from 0.5 to 2.0% on the weight of cement was based on the study by Calibara and Cabahug (2020). Based on the technical information given by the manufacturer, the typical dosage for this admixture ranged from 0.7-1.2% on the weight of cementitious or binder material; to possibly have a significant difference in the value of the compressive strengths, a variation of 0.5% was suggested.

Figure 2. The chemical admixture

2.2 Proportioning the Mixture

The concrete mix designs were based on the absolute volume method as outlined in the American Concrete Institute (1997) standard 211.1. In Table 2, the design mix for ordinary concrete with RHA cement replacement, but no admixture is shown. This served as the control mixture. Also shown in the table is the desired concrete mix with RHA cement replacement and chemical admixtures with varying amounts.

Table 2. Concrete design mix with RHA cement replacement and with and without admixture

Design mixes	No. of samples	W/C ratio	Water (L)	Cement (kg)	RHA (kg)	Sand (kg)	Coarse aggregate (kg)	Admixture (kg)
Control Mix (0% admixture)	9	0.56	12.843	20.535	2.2818	53.43	50.277	-
Design Mix-A (0.5% admixture)	9	0.56	12.843	20.535	2.2818	53.43	50.277	0.1027
Design Mix-B (1% admixture)	9	0.56	12.843	20.535	2.2818	53.43	50.277	0.2054
Design Mix-C (1.5% admixture)	9	0.56	12.843	20.535	2.2818	53.43	50.277	0.3080
Design Mix-D (2% admixture)	9	0.56	12.843	20.535	2.2818	53.43	50.277	0.4107

2.3 Procedure in Producing Concrete Specimens

2.3.1 Mixing and Molding

Mixing of specimens was performed in the Department of Civil Engineering laboratory of the University of Science and Technology of Southern Philippines – Cagayan de Oro, Cagayan de Oro City. The sampling of concrete cylinders was conducted according to the ASTM C31/C31M-19a (2019). The complete sample count was 45 cylinders of concrete. One sample set had three specimens, which represented the samples for 7, 14 and 28 days of testing.

2.3.2 Slump Testing

After mixing the concrete, the slump test (ASTM C143/C143M-15a, 2015) was performed to ensure the consistency of the concrete mixture. The records of the slump tests after the preparation of the concrete mixture were obtained to monitor the compliance of the W/C ratio.

2.3.3 Curing

The specimens were cured according to ASTM C31/C31M-19a (2019). The samples were left undisturbed for 24 h at the laboratory. The samples were protected by not exposing them to direct sunlight. After removing the samples from the mold within 30 min, they were immersed in the curing tank. Water temperature was maintained at 23 ± 2 °C.

2.4 Determination of Compression Strength

The compressive strength tests of specimens were conducted after curing periods of 7, 14 and 28 days. The compressive test of concrete samples followed the specification requirements of ASTM C39/C39M-18 (2018) and was done in a DPWH-accredited laboratory.

2.5 Statistical Analysis

The study used one-factor ANOVA, or one-way ANOVA, to determine whether the differences of the mean compressive strength results were significantly different from each other at a 5% level of significance. A post hoc T-test was performed when there was a significant difference between the sample means.

3. Results and Discussion

3.1 Compressive Strength of the Concrete Specimens

The average compressive strength of ordinary concrete mix with RHA cement replacement with and without chemical admixtures is shown in Table 3. The compressive test results showed an increasing value from the 7-, 14- and 28-day curing period.

Table 3. Compressive strength of concrete mix with
RHA cement replacement and admixtures

Design mixes	Average compressive strength (psi) Curing period (days)		
	7	14	28
Control Mix (0% admixture)	1,366	1,740	2,143
Design Mix-A (0.5% admixture)	1,303	1,303	1,616
Design Mix-B (1% admixture)	1,206	1,520	1,830
Design Mix-C (1.5% admixture)	1,470	1,760	2,353
Design Mix-D (2% admixture)	1,416	1,626	1,936

The compressive strength achieved at different ages of samples is presented in Figure 3. The study revealed that the highest value of compressive strength at 28 days was achieved by the samples added with 1.5% admixtures. This compressive strength was higher than the value obtained by the control mix. It was observed that samples with 2% admixture showed lower compressive strength than the ones with 1.5% admixture.

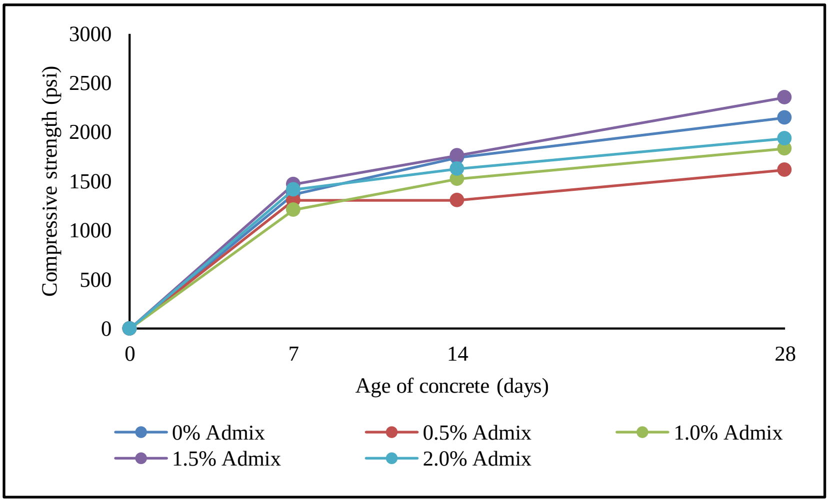

Figure 3. Average compressive strength of concrete mix with RHA cement replacement and addition of admixtures

The use of chemical admixture in concrete is extremely common nowadays (de Bem, 2018). This study revealed that the increase in compressive strength in the addition of 1.5% admixture was higher than that of 2% admixture, thereby proving that the compressive strength of concrete can be optimized by the addition of admixtures between 1.5 and 2%. However, Calibara and Cabahug (2020) stated that the 1% water-reducing admixture gave the highest compressive aggregate when the admixture was added to the concrete mixture with crushed Mangima stone as fine aggregates. The effect of admixture on the concrete mixture depends on the admixture's properties. The study of Algan (2022) highlighted that the highest compressive strengths for concrete mix were obtained by adding 0.5% naphthalene sulfonate and 0.2% lignosulfonate + naphthalene sulfonate admixtures to the 28-day aged cement mortars. In the same study, not one element of the concrete mixture was partially replaced, but only two admixtures were added.

3.2 Differences of Compressive Strengths

Table 4 shows the ANOVA of concrete cylinder samples for the 7-, 14- and 28-day curing periods with 0, 0.5, 1, 1.5 and 2% additives. The actual value of F of 11.8 (F_{actual}) was greater than the critical value of 3.885 ($F_{critical}$) indicating that the null hypothesis was rejected (i.e., there was a significant difference between the sample means).

Table 4. ANOVA of the 7, 14 and 28-day compressive strengths of concrete cylinder

Groups	SS	df	MS	F	P-value	$F_{critical}$
Between groups	989397	2	494698	11.8	0.00147	3.89
Within groups	503571	12	41964			
Total	1492968	14				

Furthermore, since the P-value of 0.00147 was less than 0.05, a post hoc T-test was performed to statistically determine the significance between the 7-, 14- and 28-day curing periods (Table 5).

Table 5. Post hoc T-test of the 7-, 14- and 28-day compressive strengths of concrete cylinder

Groups	Abs. average	LSD
7 days vs. 14 days	237.2	237.9
7 days vs. 28 days	623.2	237.9*
14 days vs. 28 days	386.0	237.9*

* indicates a significant difference at the 0.05 level of significance.

For the 7 vs. 14 days, the least squares difference (LSD) (237.9) of the former was greater than the absolute value of the mean of 237.2; hence, the null hypothesis was accepted, which statistically implied no significant findings between 7- and 14-day curing of the sample. For the 7 vs. 28 days, the LSD (237.9) of the former was less than the absolute value of the mean of 623.2. Thus, the null hypothesis was rejected; there were statistically significant findings between the 7- and 28-day curing of the sample. Furthermore, for the 14 vs. 28 days, the LSD (237.9) of the 14 days was less than the absolute value of the mean of 386.0. Therefore, the null hypothesis was rejected; there were statistically significant findings between the 14- and 28-day curing of the sample.

Table 6 shows the ANOVA of concrete cylinder samples for the 0, 0.5, 1, 1.5 and 2% admixture added to the concrete sample. The actual value of F of 15.178 (F_{actual}) was greater than the critical value of 3.106 ($F_{critical}$) indicating that the null hypothesis was rejected (i.e., there was a significant difference between the sample means). Because the P-value of 7.88E-5 was less than 0.05, a post hoc T-test was performed to determine the significance between 0, 0.5, 1, 1.5 and 2% of the admixture as an additive to the concrete sample (Table 7).

Table 6. ANOVA of the 0, 0.5, 1, 1.5 and 2% of admixture as an additive

Groups	SS	df	MS	F	P-value	$F_{critical}$
Between groups	6977407	5	1395481	15.178	0.0000788	3.106
Within groups	1103276	12	91940			
Total	8080683	17				

Table 7. Post hoc T-test of the 0, 0.5, 1, 1.5 and 2% of admixture as an additive

Groups	Abs. average	LSD
0 vs. 0.5%	342.3	539.4
0 vs. 1%	231.0	539.4
0 vs. 1.5%	111.0	539.4
0 vs. 2%	89.7	539.4
0.5 vs. 1%	111.3	539.4
0.5 vs. 1.5%	453.3	539.4
0.5 vs. 2%	252.7	539.4
1 vs. 1.5%	342.0	539.4
1 vs. 2%	141.3	539.4
1.5 vs. 2%	200.7	539.4

All percentages (from 0 vs. 0.5% to 1.5 vs. 2%) of the additives had the LSD of 539.4, which was greater than their absolute values of 342.3, 231.0, 111.0, 89.7, 111.3, 453.3, 252.7, 342.0, 141.3, and 200.7, respectively. Hence, the null hypothesis was accepted; there were no statistically significant findings on the use of the admixture as an additive to the sample.

4. Conclusion and Recommendation

This study investigated the potential of using the RHA as a partial cement replacement with the addition of chemical admixtures of varying proportions. It was found that the highest value of compressive strength of concrete was achieved by adding 1.5% admixtures to the concrete with 10% RHA partial cement replacement with a compressive strength of 2,353 psi, which superseded the control mix (2,143 psi). A 9.8% increase in compressive strength was evident as supported by ANOVA indicating a significant difference between the 7- and 28-day, and 14- and 28-day compressive strength results. This study provided information that concrete produced by utilizing cement replacements such as RHA can produce better compressive strength when chemical admixtures are considered, which can be applied to general reinforced cement concrete for sidewalks, borders and filling. It is recommended that a study to derive a cost-benefit analysis of using admixtures in concrete with RHA partial cement replacement be conducted to determine the economic value of this concrete alternative. There is also a need to carry out a similar study using a higher cement factor to determine if the compressive strength of the concrete mixture reaches the value that is required for it to be considered for use as structural concrete.

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