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# EFFECT OF RICE HUSK ASH AND CRUMB WASTE RUBBER TIRES TO MICROSTRUCTURE AND STRENGTH OF CONCRETE

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**ABSTRACT:** The study aimed to seek for alternative use of crumb waste rubber tires (CWRT) in construction to lessen its environmental impact. Its use as a component in concrete has resulted in reduced mechanical and durability performance. On the other hand, rice husk ash (RHA), when used in conjunction with ordinary Portland cement improves the mechanical properties of concrete. Hence, to exploit this influence of RHA to strength, this study incorporated RHA in concrete to compensate for the strength reduction brought about by the inclusion of CWRT, as partial replacement to fine aggregates. RHA is also a by-product of agricultural waste thus, to maximize its potential as a cementitious material, an optimized process was developed for the study. Controlled burning and grinding were employed to maximize the pozzolanic properties obtained from RHA. Chemical treatment of CWRT has not resulted in a significant increase in strength for mortar specimens thus, treatment was not employed for CWRT used in concrete. Compressive strength was tested for concrete with varying CWRT ranging from 5 to 20% fine aggregate replacement. RHA replacement of cement was fixed at 10% based on the result of an earlier related study. Concrete with 10% RHA and 5% CWRT was found to be the optimal mix with a 9.5% increase in strength compared to normal concrete.

*Keywords: Rice husk ash, Crumb waste rubber tires, Supplementary cementitious material, Alternative concrete, Amorphous silica*

## 1. INTRODUCTION

Booming construction industry is seen as a positive indicator of industrial development. However, when coupled with rapid population growth, this development yields environmental concern. Using recyclable waste materials as addition or partial replacement of materials in concrete could help in addressing this problem.

This study investigated the impact of using rice husk ash (RHA) and crumb rubber waste tires (CWRT) in concrete as a partial substitute for cement, and fine aggregates, respectively. The supply of good natural sand is in constant decline for the last 15 years [1] making it timely to look for alternatives for sand in concrete production. Several studies [2,3] had shown the suitability of CWRT as a construction material. However, a notable decline in mechanical properties, particularly in compression and tension, was also observed when CWRT was used in concrete [4,5]. Workability is also affected when CWRT was used in concrete [6]. Hence, there's a need to address this impact of CWRT to reduce some of the mechanical properties of concrete.

The partial addition of rice husk ash (RHA) in concrete had shown better mechanical properties compared to concrete with pure Portland cement [7]. This offered a potential solution to improve the performance of concrete with CWRT. RHA is a natural carbon by-product of rice husk when converted into ash through burning. When burning is done in a controlled condition, RHA can have high amorphous silica ($SiO_2$) and pozzolanicity comparable to that of silica fume [8] making RHA a potential supplementary cementitious material (SCM) in concrete production [9]. The increase in compressive strength observed in concrete with RHA as partial replacement to cement can be attributed to the filler effect as RHA's fine particles acted as micro fillers enhancing the cement paste pore structure resulting in a denser concrete mix contributing to the overall strength development of the concrete [10].

## 2. MATERIALS AND METHODS

Except for RHA, and CWRT, all raw materials used in making mortar and concrete specimens were procured from the local hardware. Rice husk was obtained from Gapan, Nueva Ecija, Philippines. CWRT, grounded to fine aggregates size already, was procured from a local company that ventures in recycling scrap rubber.

### 2.1 Material Preparation And Physical Properties

Raw rice husk was subjected to controlled burning and subsequent grinding to produce the desired quality RHA. Details of burning and grinding process, as well as properties and performance of derived RHA from an optimized procedure of burning

Table 1 Concrete Mix Proportions

| Mix ID | Cement | Water | RHA | Fine Aggregates | CWRT | Coarse Aggregates |
|---|---|---|---|---|---|---|
| Control (0RHA 0CWRT) | 4.37 | 2.19 | 0.0 | 6.52 | 0.0 | 10.64 |
| C (0RHA 5CWRT) | 4.37 | 2.19 | 0.0 | 6.20 | 0.22 | 10.64 |
| R (10RHA 0CWRT) | 3.93 | 2.19 | 0.39 | 6.52 | 0.0 | 10.64 |
| RC1 (10RHA 2.5CWRT) | 3.92 | 2.19 | 0.39 | 6.36 | 0.11 | 10.64 |
| RC2 (10RHA 5CWRT) | 3.93 | 2.19 | 0.39 | 6.20 | 0.22 | 10.64 |
| RC3 (10RHA 7.5CWRT) | 3.93 | 2.19 | 0.39 | 6.03 | 0.33 | 10.64 |
| RC4 (10RHA 10 CWRT) | 3.93 | 2.19 | 0.39 | 5.87 | 0.42 | 10.64 |

Note: All measurements in kilograms (kg)

and grinding of rice husk was reported in [11]. To establish RHA's chemical composition, mineralogical form, and microstructure, X-Ray Fluorescence spectrometry (XRF), X-Ray diffraction (XRD), scanning electron microscopy (SEM) were performed.

CWRT was initially treated chemically with sodium hydroxide (NaOH) solution at varying duration ranging from 10 to 30 minutes to determine the optimum treatment duration. The 20-min treatment with NaOH yielded better results but nullified since a statistical test revealed that the improvement exhibited was not significant. Thus, untreated CWRT was employed in succeeding specimen preparation and testing instead.

Procured aggregates were sieved in accordance with ASTM C136. The nominal maximum size of the coarse aggregates (CA) used was 19-mm with a fineness modulus of 2.79 whereas the fine aggregates (FA) had a fineness modulus of 2.95. Performing ASTM C127 and C128, the specific gravity of CA and FA was found to be 2.789 and 2.343, respectively. Since CWRT is a replacement for fine aggregates, a similar procedure was employed to it and obtained its maximum size to be 2.36mm and with a fineness modulus of 4.15. The unit weight of aggregates was determined in accordance with ASTM C29 and found to be 1682 kg/m$^3$ and 1574 kg/m$^3$ for CA and FA, respectively.

### 2.2 Experimental Setup

This study was divided into four phases: preparation and quality assessment of RHA, pretreatment and quality assessment of CWRT, preparation, and testing of mortar specimens, and preparation of concrete specimens with RHA and CWRT, testing for compression and assessing concrete's microstructure by SEM. The first was reported in [11]; while pretreatment and quality assessment of CWRT was reported in the previous section.

In preparing mortar specimens, ASTM C109 was followed. Two sets of mortar were prepared; one for mortar with RHA, and another with CWRT. For RHA mortar, 5% to 20% cement replacement, at 5% interval, were investigated with six (6) mortar samples each. A controlled set (i.e. 0% RHA) was also prepared with 6 samples. For CWRT mortar, 6 samples were prepared for control (0% CWRT) and another 6 mortar samples for 10% CWRT replacement of fine aggregates. Mortar with RHA specimens was tested for physical properties, microstructure, and compression. The RHA amount that yielded the highest compressive strength sets the amount of replacement of RHA for cement in concrete specimens. From mortar tests, it was determined that RHA in concrete was optimal at 10% replacement by weight of cement.

Concrete was prepared in accordance with ASTM C39 while ACI 211.1 was used in determining the concrete mix proportions (see Table 1). Water to cement (w/c) ratio of 0.5 was adopted. CWRT was varied from 0 to 10% at 2.5% interval. Six (6) concrete cylinder samples were made for each varying CWRT, for a total of 42 concrete cylinders, tested for compression on the 28$^{th}$ day. Concrete was tested for compression in compliance with ASTM C39.

## 3. RESULTS AND DISCUSSION

### 3.1 Properties of RHA

Physical, microstructure, and chemical test results for RHA were reported in [11]. The recovered RHA was pinkish-white in color as shown in Fig. 1. The chemical composition of RHA, using X-Ray Fluorescence spectrometry (XRF), was tabulated and compared against ordinary Portland cement (OPC) (Table 2). XRF result showed that RHA produced has 93.47% SiO2 which was comparable to other studies. This satisfied ASTM C618 (Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete) chemical requirement for class N pozzolan. During hydration, RHA acts as a pozzolanic material that reacts to available $Ca(OH)_2$ to produce secondary type calcium-silicate-hydrate (C-S-H) which aids in improving concrete strength and durability [12]. However, the hydration reactivity of RHA depends largely on its amorphous mineralogical form.

Table 2 Chemical composition of RHA and OPC

| Oxide Composition (%) | RHA | OPC |
|---|---|---|
| Silicon dioxide ($SiO_2$) | 93.47 | 19.6 |
| Aluminum oxide ($Al_2O_3$) | 0.92 | 5.20 |
| Ferric oxide ($Fe_2O_3$) | 1.08 | 3.20 |
| Calcium oxide (CaO) | 0.87 | 64.8 |
| Magnesium oxide (MgO) | 3.18 | 1.40 |
| Sodium oxide ($Na_2O$) | - | 0.40 |
| Titanium oxide ($TiO_2$) | 0.04 | - |

The presence of silica alone is not sufficient to ensure pozzolanic activity as its form may not promote it. For silica's pozzolanic to get activated, it must come in amorphous form [13]. According to [12], the amorphous form of silica in RHA is the reactive structure that participates in cement hydration to produce secondary type C-S-H gel. X-ray diffraction (XRD) analysis result in Fig. 2, as reported in [11] showed that the produced RHA in this study was amorphous in form. The result of SEM was also reported in [11].

Fig. 1 Pinkish-white color of RHA

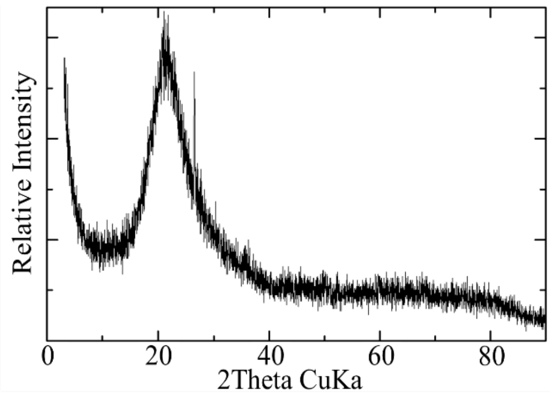


Fig. 2 XRD analysis of RHA

### 3.2 RHA Mortar Test Results

The incorporation of RHA in mortar decreases flowability. In the study [11], they tested the flowability of mortar with increasing RHA content and observed a decreasing flowability, i.e. flow diameter, with increasing RHA. With no RHA in the mortar, flow diameter was recorded at 175mm then it gradually decreases down to 0mm at 20% RHA replacement of cement in mortar mix. The behavior was attributed to RHA particles' high surface area leading to high water absorption.

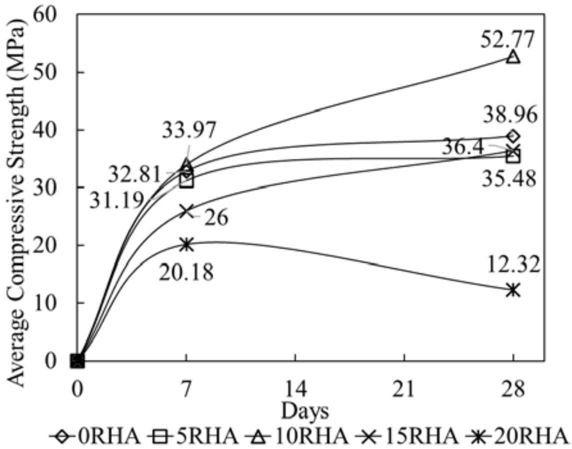


Fig. 3 Comparison of compressive strengths obtained for 7 and 28 days of RHA blended cement concrete mortars

The compression test of RHA mortars revealed that incorporation of RHA as cement replacement can only be maximized at 10% [11] as seen in Fig. 3. Mortar with 15% RHA still gained strength from 7 to 28 days but it was far below that of mortar with 10% RHA. Mortar with 20% performed the poorest among all mortar mix right from the onset. The mortar with RHA also revealed that with 10% RHA, the strength of mortar can be comparable or even higher than that of mortar with only Portland cement. Mortar with pinkish-white RHA resulted in a mortar compressive strength of 33.97 MPa while that of mortar with blackish RHA yielded 27.32 MPa [11].

### 3.3 CWRT Mortar Test Results

In the study of [14], NaOH was seen as a possible solution to address the poor rubber-cement interface adhesion possibly due to zinc stearate. Thus, pre-treatment using NaOH to address the hydrophilicity of crumb waste rubber tire (CWRT) particles was initially explored. Soaked in NaOH solution, the duration of treatment was explored as earlier mentioned. Treatment with NaOH for 20-min turned out to have the highest compressive strength in mortar samples (shown in Fig. 4), however, statistical analysis showed that the strength difference compared to other duration period and control sample, did not vary significantly thus the study proceeded with the use of untreated CWRT.

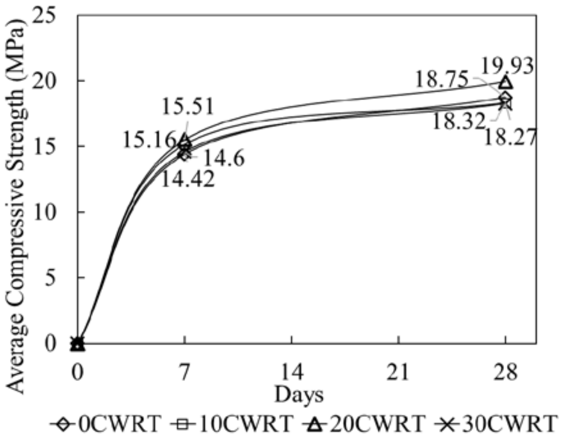


Fig. 4 Comparison of compressive strengths obtained for 7 and 28 days of CWRT mortars

### 3.4 Concrete With RHA And CWRT

*3.4.1 Compression tests*

All compression test samples were tested on the 28th day. It was evident that CWRT decreases the compression strength of concrete, as shown clearly in Table 3. Without CWRT, i.e. control and R samples, compressive strengths were recorded at 28.98 and 34.89 MPa, respectively. But with increasing CWRT, from 2.5 to 10% at 2.5% interval, it decreased from 34.89 MPa to 22.66 MPa. The effect of RHA can be observed by comparing control samples with "R" samples, and "C" samples with "RC2". The former comparison showed "R" samples with higher compressive strength (34.89 MPa against 28.98 MPa), while the latter showed "RC2" with 31.72 MPa strength compared to 25.54 MPa for "C" samples. This clearly showed that the incorporation of RHA in concrete, with or without CWRT, increases the compressive strength.

Based on compressive strength tests, RHA improves the strength of concrete while the presence of CWRT reduces it. However, with CWRT limited to 5%, concrete can still have comparable or slightly better compressive strength than concrete without RHA and CWRT (control).

*3.4.2 SEM of concrete with RHA and CWRT*

Figure 5A is SEM photographs of R, and samples with varying CWRT ('RC'). No visible gap or notable crack can be seen. Figure 5B is a micrograph of RC1 (10RHA 2.5CWRT) at x200 magnification. The presence of notable crack is attributed to the incorporation of CWRT in concrete. CWRT is known to have a smooth surface that deters bonding between CWRT surface and the cement matrix. Figure 5C is for concrete with 10% RHA and 5% CWRT. It also exhibited a notable gap between CWRT surface and the cement matrix.

Figure 5D represents SEM micrographs of concrete with 10% RHA and 7.5% CWRT, while Fig. 5E is for concrete with 10% RHA and 10% CWRT. It can be observed from these photos the presence of notable gaps or wide cracks which are attributed to the presence of CWRT in concrete.

Though the increase in crack size as CWRT amount in concrete increases cannot be established in these SEM photos, it is still evident that concrete samples with CWRT are consistently exhibiting noticeable cracks.

Table 3 Compressive strength of concrete with 10% RHA and varying amount of CWRT

| Mix ID (%RHA/%CWRT) | Compressive strength (MPa) |
|---|---|
| Control (0RHA/0CWRT) | 28.98 |
| C (0RHA/5CWRT) | 25.54 |
| R (10RHA/0CWRT) | 34.89 |
| RC1 (10RHA/2.5CWRT) | 32.18 |
| RC2 (10RHA/5CWRT) | 31.72 |
| RC3 (10RHA/7.5CWRT) | 24.92 |
| RC4 (10RHA/10 CWRT) | 22.66 |

## 4. CONCLUSION

The use of CWRT in concrete had been shown to reduce the mechanical properties of concrete. RHA, on the other hand, as a supplementary cementitious material had been shown to improve concrete's strength. Thus, this study explored the potential of RHA to counter the negative effect of CWRT when these two materials are incorporated in the production of concrete. Some notable findings are as follows: (1) To maximize the potential of RHA, rice husk must be converted into RHA that is highly pozzolanic and reactive. This was achieved by burning at the range of 400 to 600 C, with slow cooling for 6-8hrs, and finally, grinding for 2 hours. About 93.5% of silica was found in RHA and its mineralogical form was found to be amorphous. The recovered RHA was pinkish-white; (2) Incineration of RH beyond 600 C resulted in excessive burning which produced blackish RHA. Blackish RHA resulted in RHA mortar with lower compressive strength compared to RHA mortar with pinkish-white RHA; (3) RHA in mortar affected flowability, as increasing RHA resulted in decreasing flowability. At 20% RHA, flowability was recorded


Fig. 5 (A to E) SEM photographs of concrete with 10% RHA and varying CWRT. (A) 10RHA/0CWRT, (B) 10RHA/2.5CWRT, (C) 10RHA/5CWRT, (D) 10RHA/7.5CWRT, (E) 10RHA/10CWRT

In terms of compressive strength, mortars with 10% RHA showed to have the highest compressive strength; (4) Pre-treatment of CWRT with NaOH solution showed to have resulted to the highest compressive strength from mortar with CWRT treated for 20-min. However, statistical analysis showed the difference between strength results to be not significant; (5) RHA and CWRT in concrete resulted in lower workability with increasing CWRT. Air content also increases with increasing CWRT; (6) Maximizing the amount of CWRT that can be used in concrete without compromising strength properties showed 5% CWRT with 10% RHA was the optimal mix for concrete.

Critical investigations and further improvements of the study are advised for future researchers to better emphasize and enhance the mechanical properties of concrete containing RHA and CWRT. As observed in the preparation stage of RHA, the burning temperature given was only in terms of a range, it is therefore suggested that specific temperatures either within or outside the specified range and the corresponding effect of these temperatures to concrete mortars be investigated to identify concisely the other pozzolanic characteristics of RHA. Also, the rate of cooling of the material can be improved. Other various proportions of CWRT and/or RHA to partially replace concrete components other than those employed in this study may be explored. For the surface modification of rubber particles, Sodium Hydroxide was the only chemical solution utilized in this study. Thus, it is encouraged that other treatments and the various processes involved with them also be inspected.

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