# d_compressive_strength_of_unprocessed_rice_husk_ash_concrete.pdf

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**ORIGINAL PAPER**

# Abrasion resistance and compressive strength of unprocessed rice husk ash concrete

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## Abstract

This paper investigates the effects of adding natural rice husk ash collected from uncontrolled burning and without previous grinding (NRHA) as cement replacement in concrete. To obtain an adequate particle size, NRHA was mixed with coarse aggregate for a convenient period of time before adding the other components. Compressive strength, water absorption, porosity, and abrasion resistance expressed as weight loss were examined. Test results showed that decreasing the particle size through mixing with coarse aggregate improved the compressive strength, reduced the permeability, and increased the abrasion resistance of concrete. By mixing NRHA with aggregate for 8 min, abrasion resistance improved by 10.35 and 23.62% over the control concrete at 28 and 91 days, respectively. Incorporating NRHA in concrete by grinding with coarse aggregate during the mixing process could be suitable for making normal-strength concrete and for applications where abrasion resistance is an important parameter. In addition, using NRHA as a partial replacement cement contributes to the reduction of $CO_2$ emissions due to the production of cement.

**Keywords** Compressive strength · Abrasion resistance · Rice husk ash · Concrete

## Introduction

Indonesia is one of the largest rice-producing countries in the world; in 2016, rice production in the country reached 79.10 million tons (KEMENTAN 2017). Of this amount, 42.5 million tons was rice, and the rest was rice husk. Rice husk is mainly used as biofuel to power boilers and produce steam for drying in the parboiling process, and for energy generation. However, in rural areas of Indonesia, rice husk is generally burned and left as waste in open areas adversely affecting the environment.

The use of rice husk ash (RHA) in concrete production has been researched for several decades. It has been found that utilizing RHA as a cement replacement in concrete improves its strength and durability properties, reduces materials cost due to cement savings, produces environmental benefits related to the disposal of waste materials, and reduces $CO_2$ emissions (Ramasamy 2012; Sarawathy and Song 2007; Chao-Lung et al. 2011; Nehdi et al. 2003; Sensale 2006; Giaccio et al. 2007; Kondraivendhan 2013). Kannan (2015) studied the compressive strength and UPV of self-compacting concrete incorporating RHA and Metakaolin and concluded that the combination of RHA and metakaolin act as highly reactive pozzolanic material in SCC. Highly reactive RHA is obtained when RHA is burned under controlled conditions (Mehta 1994; Givi et al. 2010; Rukzon et al. 2009; Sensale 2006; Nehdi et al. 2003)

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and by increasing the fineness of RHA (Bui et al. 2005; Habeeb and Fayyadh 2009). This reactivity is attributed to the high content of amorphous silica and the very large surface area governed by the porous structure of the particles (Della et al. 2002). In an uncontrolled burned condition and without previous grinding, residual RHA is produced with lower quality due to high carbon content. The high carbon content leads to an increase in water demand and produces a darker color of mortar and concrete. However, by grinding it to an appropriate particle size, the pozzolanic reactivity of residual RHA can be improved; however, the process has considerable costs (Zerbino et al. 2011; Chao-Lung et al. 2011; Sensale 2006).

Zerbino et al. (2011) investigated the possibility of improving the quality of residual RHA without previous grinding by simply mixing it with coarse aggregate for a convenient period of time prior to adding other concrete components. The test results showed that the replacement of 15% of cement with residual RHA achieved similar mechanical (compressive strength and modulus of elasticity) and durability properties (creep, shrinkage and permeability) compared to control concrete sample. By adopting this method, residual RHA without previous grinding can be used to produce normal-strength concrete.

As a developing country, infrastructure development has been reached some rural areas in Indonesia. In such areas, a conventional concrete with compressive strength of 20 MPa commonly used for structural concrete as specified per SNI-03-2847 (2013). Unprocessed RHA is a viable alternative as cement replacement in concrete together with an optimized mixing duration to achieve a desired particle size. The pozzolanic reactivity of RHA was influenced by the particle size. This research focuses investigating the influence of grinding unprocessed RHA with coarse aggregates on compressive strength, water absorption, porosity, and abrasion resistance of conventional concrete. The results of the study would be beneficial for producing alternative low-cost, but high quality building and pavement materials in the rural areas.

## Experimental procedures

### Materials

Portland composite cement (PCC) conforming to Indonesian standard SNI 7064 (2014) and with specific gravity of 3.08 was used in this investigation. The PCC equivalent with CEM Type II/A-M cement contains 80% clinker and 20% mineral admixture, including ground granulated blast furnace slag, silica fume, fly ash, and gypsum (Caronge et al. 2017; Adnan et al. 2017; Tjaronge et al. 2014). Natural river sand with a fineness modulus of 2.77 and a specific gravity of 2.58 was used as fine aggregate. Coarse aggregate was crushed stone with a maximum size of 20 mm and specific gravity of 2.83. Residual RHA obtained from open-field uncontrolled burning at Gowa, South Sulawesi, Indonesia and without previous grinding was used. The residual NRHA used in this investigation is shown in Fig. 1. It can be clearly seen that in Fig. 1, the size and shape of NRHA make it difficult to obtain an excellent pozzolanic reaction and significantly increases water demand. In general, the pozzolanic effect depends on not only the pozzolanic reaction but also the filler effect of the smaller particles in the mixture (Isaia et al. 2003). Therefore, they can be mixed with coarse aggregates and ground to obtain an adequate RHA particle size due to the weak bonds of NRHA particles shown in Fig. 1. A high-range polycarboxilic-based superplasticizer (SP) was used to maintain slump in the range of 80–100 mm.

**Fig. 1** Residual NRHA after burning process

### Mixture proportions

The control mixture was designed as a conventional concrete to have compressive strength of 20 MPa at 28 days according to SNI 03-2834 (2002). The ratio of concrete mix proportion was 1:1.88:2.83; 1 part cement, 1.88 fine aggregates and 2.83 coarse aggregates with constant water to cement ratio of 0.58. The NRHA replacement was 15% by weight of the cement. The control and NRHA mixture were mixed using the following manner. Cement/NRHA, sand and coarse aggregate were dry mixed for 1 min before adding water and super plasticizer. All components were mixed again for 2 min and then mixed manually for 1 min. The fresh concrete was mixed again for 2 min before placing it in molds. To reduce the particle size, the NRHA was dry mix with coarse aggregate for 5 min (5mNRHA) and 8 min (8mNRHA) before the remaining materials were added. Then, similar mixing procedures of the control and

**Table 1** Mixture proportion of concrete

| Mixture | Water (kg/m$^3$) | Cement (kg/m$^3$) | NRHA (kg/m$^3$) | Fine aggregates (kg/m$^3$) | Coarse aggregates (kg/m$^3$) | SP (kg/m$^3$) |
|---|---|---|---|---|---|---|
| Control | 215 | 371 | 0 | 698 | 1047 | 0 |
| NRHA | 215 | 315 | 56 | 698 | 1047 | 2.2 |
| 5mNRHA | 215 | 315 | 56 | 698 | 1047 | 1.7 |
| 8mNRHA | 215 | 315 | 56 | 698 | 1047 | 1.4 |

NRHA mixture were adopted. Table 1 summarizes the concrete mixture proportions.

## Testing methods

The slump value of concrete was measured according to ASTM C143 (2015). Compressive strength and modulus elasticity of concrete were measured on three cylindrical specimens of ∅100 × 200 mm at 28 and 91 days water curing per ASTM C469 (2014) and ASTM C39 (2017), respectively.

The water absorption and porosity values were tested at 91 days water curing according to ASTM C642-97 (2013). For this test, cylindrical specimens with dimensions of ∅100 × 000 mm were prepared; these were cut from a cylindrical specimen with dimensions of ∅100 × 200, leaving the top height of 50 mm and a bottom height of 50 mm. Specimens were dried in an oven at 105 °C until a constant weight ($W1$) was obtained. Then, the specimens were immersed in water for 48 h to achieve a saturated surface-dry condition, and their weights were recorded ($W2$). The water absorption of the specimen (WA) was calculated by Eq. 1. The dry bulk density (DBD) and porosity ($P$) values were calculated using Eqs. 2 and 3, respectively.

$$\mathrm{WA} = \frac{(W2 - W1)}{W1} \times 100 \tag{1}$$

$$\mathrm{DBD} = \frac{W1}{V} \tag{2}$$

$$P = \left[1 - \frac{\mathrm{DBD}}{\gamma}\right] \times 100, \tag{3}$$

where $V$ is the volume of the specimens and $\gamma$ is the saturated surface drying density of the specimens.

The abrasion resistance was tested using the Los Angles abrasion machine per EN1097-2:2007 (2007) (Fig. 2). Concrete specimens were cast into prism molds with dimensions of 100 × 100 × 400 mm. After 28 and 91 days, the prism specimens were removed from water and then cut to obtain 50 × 50 × 50 mm$^3$ specimens for abrasion testing (Fig. 3). In this test, eight specimens measuring 50 × 50 × 50 mm$^3$ were placed in the Los Angles abrasion machine together with eight steel spheres and allowed to rotate to 1000 rotations. The specimens were weighed every 100 rotations to measure weight change. Previous studies by Fernando and Said (2011), Rao et al. (2016a) and (b) also used Los Angeles test to evaluate the abrasion resistance of concrete.

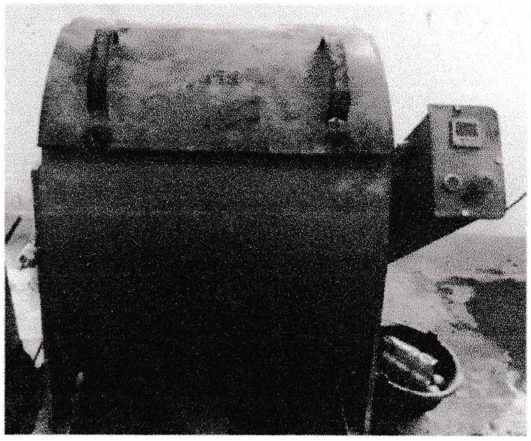


**Fig. 2** Los Angles machine for abrasion test

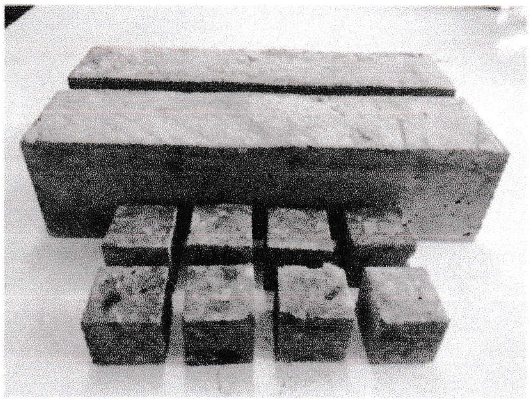


**Fig. 3** Specimens for abrasion testing

## Results and discussion

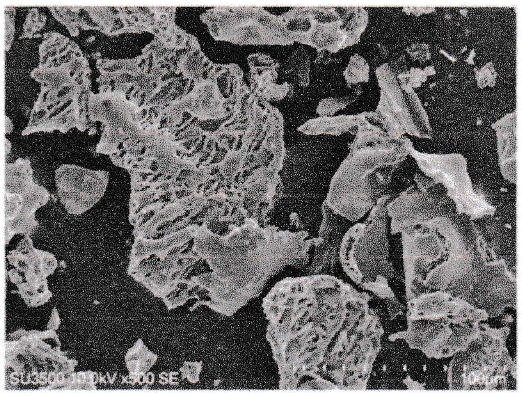
### Effects of grinding on NRHA characteristics

Decreasing the particle size is a common method for improving the pozzolanic activity of mineral admixture. The effect of grinding on surface structure of NRHA samples by SEM imaging is shown in Fig. 4. NRHA has a porous cellular structure and irregular shaped with sizable fraction. Average particle size of NRHA is 228 μm. Similar results were obtained by Ponmalar and Abraham (2015) who found the particle size of natural RHA is 140–240 μm. After grinding with coarse aggregate, the 5mNRHA and 8mNRHA consists mainly of fine irregular shaped particle with average particle size of 97 and 82 μm, respectively. By this way, the average particle size of NRHA can be decreased and similar finding was also reported by some investigations (Zerbino et al. 2011). In addition, there are no significant differences in chemical composition between NRHA, 5mNRHA and 8mNRHA after grinding with coarse aggregates as shown in Table 2. Rukzon et al. (2009) also found the same observation in chemical composition of RHA with different fineness from the same batch. Van et al. (2013) reported that the particle size of RHA clearly decreases with increasing grinding time and strongly influenced the compressive strength development of concrete.

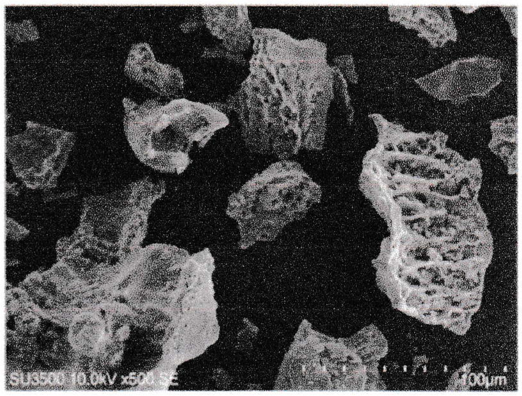
### Fresh properties of concrete

The fresh properties of concrete with and without RHA are presented in Table 3. It can be seen that the NRHA concrete required a higher dosage of SP than 5mNRHA and 8mNRHA to achieve the desired slump value. This is due to the high specific surface area and high carbon content (Zerbino et al. 2011; Cordeiro et al. 2009; Ponmalar and Abraham 2015). However, a significant reduction of SP demand was found in 5mNRHA and 8mNRHA concrete. This indicates that the mixing optimization is important when NRHA is used as a replacement for cement. The decreases the particle size of NRHA caused the water demand of the mixture decrease. Similar results have been reported by other authors (Chao-Lung et al. 2011; Rukzon et al. 2009; Zerbino et al. 2011).

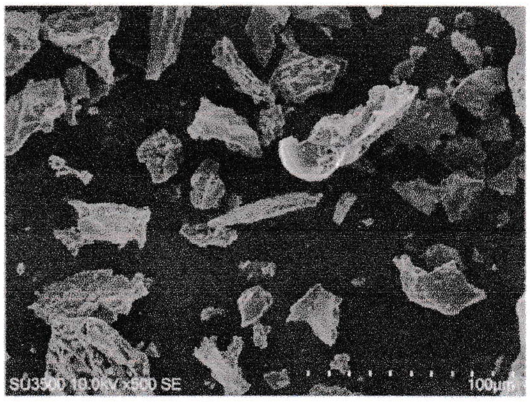
Table 3 shows the average fresh densities of concrete. It can be seen in Table 3 that fresh density was in the range of 2287–2365 kg/m$^3$. The fresh density of concrete decreased with the addition of NRHA due to its low density, which led to a reduction in the mass per unit volume. It was also observed that the fresh density increased with an increase in the grinding time for NRHA and coarse aggregate. This is due to the reduction of NRHA particle size, which resulted in a denser concrete matrix.



(**a**) NRHA



(**b**) 5mNRHA



(**c**) 8mNRHA

**Fig. 4** SEM imaging NRHA at various grinding

**Table 2** Chemical compound of PCC, NRHA, 5mNRHA and 8mNRHA

| Item | PCC | NRHA | 5mNRHA | 8mNRHA |
|---|---|---|---|---|
| Silicon dioxide ($SiO_2$), % | 18.39 | 60.35 | 60.87 | 61.03 |
| Aluminum oxide ($Al_2O_3$), % | 5.15 | 2.50 | 2.33 | 2.17 |
| Iron oxide ($Fe_2O_3$), % | 3.41 | 0.28 | 0.28 | 0.29 |
| Sulfur trioxide ($SO_3$), % | 1.81 | 0.01 | 0.01 | 0.01 |
| Magnesium oxide (MgO), % | 0.99 | 0.41 | 0.40 | 0.39 |
| Calcium oxide (CaO), % | 61.79 | 0.14 | 0.22 | 0.28 |
| Loss on ignition (LOI), % | 4.61 | 45.12 | 44.92 | 44.76 |
| Particle size (μm) | 17.2 | 228 | 97 | 82 |

**Table 3** Fresh and strength properties of concrete

| Mixture | SP (kg/m$^3$) | Slump (mm) | Fresh density (kg/m$^3$) | Compressive strength (MPa) | | Modulus of elasticity (GPa) | |
|---|---|---|---|---|---|---|---|
| | | | | 28 days | 91 days | 28 days | 91 days |
| Control | 0 | 90 | 2365 | 20.83 | 25.31 | 20.3 | 21.6 |
| NRHA | 2.2 | 90 | 2287 | 19.93 | 20.31 | 19.4 | 20.6 |
| 5mNRHA | 1.7 | 95 | 2293 | 22.21 | 26.56 | 21.2 | 22.1 |
| 8mNRHA | 1.4 | 90 | 2307 | 24.21 | 30.21 | 21.7 | 22.8 |

## Compressive strength and modulus of elasticity

The compressive strength of NRHA is lower than the control concrete at all ages (see Table 3); this is caused by low pozzolanic activity of NRHA due to its coarser particles. The coarser particles of RHA produced larger pores in the cement paste, thus reducing the compressive strength of concrete. On the other hand, mixing NRHA with coarse aggregate for 5 and 8 min (5mNRHA and 8mNRHA) significantly improves the compressive strength compared to NRHA. At 28 days, compressive strength with respect to NRHA increased by 17.33 and 27.89% for 5mNRHA and 8mNRHA, respectively, whereas strength increased by 30.77 and 48.74%, respectively, at 91 days. The increase in compressive strength was due to the reduction of particle size of the ash in the mixing process, which in turn reduces the volume of larger pores in the cement paste. By grinding, residual RHA can improve, reducing the adverse effect of the high carbon content in the ash and increasing the homogeneity of the material (Sensale 2006; Cordeiro et al. 2009). Compared to the control concrete, 5mNRHA showed equal compressive strength at 28 and 91 days. For 8mNRHA, the compressive strength of concrete at 28 and 91 days increased by 16.22 and 19.36%, respectively. The increase in compressive strength can be attributed to the amorphous silica and the fine particle size of RHA, which provided excellent pozzolanic activity. As a consequence, the hydration process is accelerated and larger volumes of reactive products are formed (Ganesan et al. 2008; Givi et al. 2010). The physical properties of RHA, especially particle size, influence its reactivity. Generally, reactivity of RHA increases with decreasing particle size and vice versa.

The modulus of elasticity of 5mNRHA and 8mNRHA was higher than the control concrete at all ages. At 28 days, the modulus of elasticity of 5mNRHA and 8mNRHA was higher than the control concrete (20.3 GPa) by about 4.43 and 6.89%, respectively. It can be seen that the modulus of elasticity of all concrete continued to increase with age (Table 3). At 91 days, the percentage increase in the modulus of elasticity was 4.25–6.40%. However, the maximum value of modulus elasticity occurred for8-mNRHA at all ages due to the increased reactivity of NRHA by grinding with coarse aggregate.

In addition, failure behavior was similar for all concrete specimens with and without NRHA under uniaxial compression. However, cracks were observed at comparatively lower stress in 5mRHA and 8mNRHA concrete than control concrete (Fig. 5). From the test results, NRHA can be potentially used as replacement for cement to produce normal-strength concrete by adapting the mixing process to obtain an adequate particle size. Zerbino et al. (2011) reported similar results with replacement of cement with 15% NRHA.

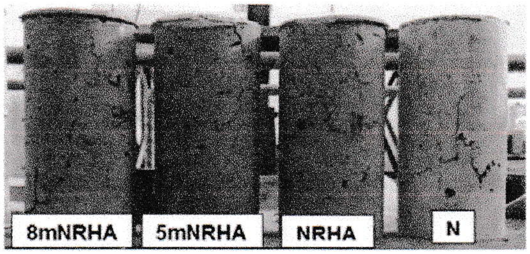


**Fig. 5** Typical failures of specimens under compression

## Water absorption and porosity

The test results for water absorption and porosity of concrete with and without RHA at 91 days are shown in Table 4. The percentage of water absorption of NRHA concrete decreased with increasing optimization times in the mixing process. The water absorption values for NRHA, 5mNRHA and 8mNRHA were 6.28, 5.58 and 4.73%, respectively. In addition, 8mNRHA concrete exhibited water absorption about 15.69% less than control concrete.

Similar behavior was observed in regard to porosity value. The porosity values for NRHA, 5mNRHA and 8mNRHA were 8.87, 5.71 and 3.56%, respectively. On the other hand, 8mNRHA concrete reduced the porosity value by about 29.21% compared to control concrete. This is mainly due to the pozzolanic action of RHA and the pore-refining capacity of RHA in concrete (Givi et al. 2010; Rukzon and Chindaprasirt 2008). Further, with prolonged curing (90 days), the addition of RHA leads to a reduction of permeable voids (Ganesan et al. 2008).

## Abrasion resistance

Abrasion resistance data for concrete at 28 and 91 days are shown in Table 5 and Fig. 6. Generally, the weight loss of concrete with and without RHA decreased with age, indicating better abrasion resistance. This can be mainly attributed to the increase in compressive strength caused by increased concrete maturity (Naik et al. 2002; Yen et al. 2007).

**Table 4** Water absorption and porosity values at 91 days

| No | Mix | Water absorption (%) | Porosity (%) |
|---|---|---|---|
| 1 | N | 5.61 | 5.41 |
| 2 | NRHA | 6.28 | 8.87 |
| 3 | 5mNRHA | 5.58 | 5.71 |
| 4 | 8mNRHA | 4.73 | 3.56 |

Figures 7 and 8 show the weight loss and appearance of concrete after 1000 full rotations, respectively. It was found that the weight loss for control concrete was 61.55 and 56.55% at 28 and 91 days, respectively. The weight loss was 79.40 and 72.40% for NRHA, 60.23 and 53.23% for 5mNRHA, and 55.18 and 43.18% for 8mNRHA at 28 and 91 days, respectively. The replacement of cement with 15% NRHA with 8 min optimization during the mixing process (8mNRHA) significantly improved the abrasion resistance of concrete by about 10.35 and 23.62% over control concrete at ages of 28 and 91 days. This is due to the pozzolanic reaction and the micro filler effect of RHA. The micro filler effect of RHA distributes the hydration products in a more homogeneous fashion in the available space, which makes the matrix much denser (Ramasamy 2012; Rao and Rao 2003). Thus, compressive strength and abrasion resistance of concrete increased with the addition of RHA.

## Relationship between strength properties and abrasion resistance

Figures 9 and 10 show the relationship between weight loss, compressive strength and modulus of elasticity of all concrete by age. The figure clearly shows that weight loss decreases as compressive strength and modulus of elasticity increase. This means that compressive strength and modulus of elasticity are the most important factors governing the abrasion resistance of concrete. Increasing the compressive strength and modulus of elasticity lead to an increase in the abrasion resistance of concrete (Naik et al. 1995; Laplante et al. 1991; Atis 2002; Li et al. 2006; Singh and Siddique 2012). A polynomial relationship seems to best fit data with $R^2$ values greater than 0.85 to determine the relationship between abrasion resistance, compressive strength and modulus of elasticity. The high value of the correlation coefficient indicates that abrasion resistance has a strong relationship with compressive strength and modulus of elasticity. The best regression of the relationship between abrasion resistance, compressive strength and modulus of elasticity is polynomial has been reported by other authors (Siddique and Khatib 2010; Konin and Kouadio 2012; Siddique et al. 2012; Turk and Karatas 2011).

## Conclusions

The following conclusions can be drawn from this investigation.

**Table 5** Abrasion weight loss of concrete at 28 and 91 days

| Full rotations | Weight loss (%) at 28 days | | | | Weight loss (%) at 91 days | | | |
|---|---|---|---|---|---|---|---|---|
| | N | NRHA | 5mNRHA | 8mNRHA | N | NRHA | 5mNRHA | 8mNRHA |
| 100 | 8.75 | 11.22 | 9.49 | 8.52 | 5.75 | 9.22 | 7.49 | 6.52 |
| 200 | 15.30 | 19.48 | 14.03 | 12.82 | 12.30 | 17.48 | 13.03 | 10.82 |
| 300 | 21.13 | 26.73 | 19.85 | 17.68 | 18.13 | 23.73 | 18.85 | 14.68 |
| 400 | 26.03 | 31.89 | 24.75 | 20.97 | 23.03 | 29.89 | 23.75 | 18.97 |
| 500 | 31.82 | 38.39 | 30.28 | 27.23 | 28.82 | 36.388 | 28.28 | 22.23 |
| 600 | 37.19 | 45.88 | 35.27 | 33.27 | 35.19 | 42.88 | 33.27 | 26.27 |
| 700 | 44.38 | 54.44 | 43.17 | 39.73 | 41.38 | 50.44 | 38.17 | 30.73 |
| 800 | 49.87 | 61.70 | 48.99 | 44.94 | 45.87 | 58.69 | 43.99 | 34.94 |
| 900 | 55.60 | 69.79 | 54.71 | 49.66 | 52.60 | 64.79 | 48.71 | 39.66 |
| 1000 | 61.55 | 79.40 | 60.23 | 55.18 | 56.55 | 72.40 | 53.23 | 43.18 |

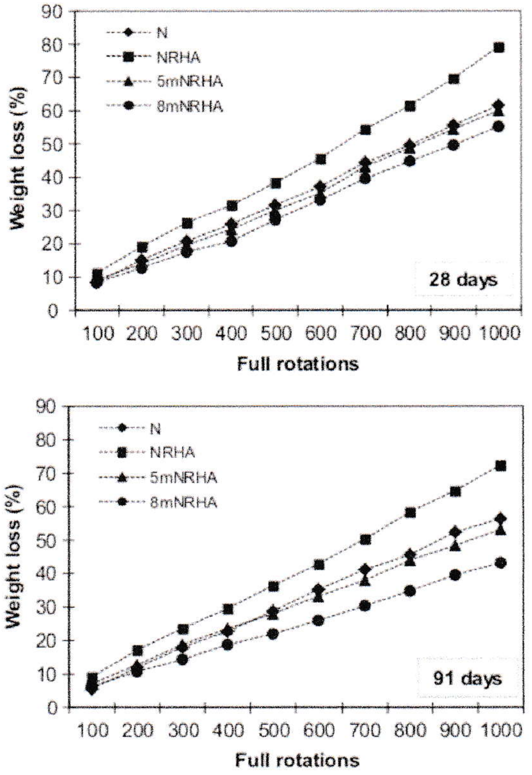


**Fig. 6** Abrasion resistance of concrete with the Los Angles test at 28 and 91 days

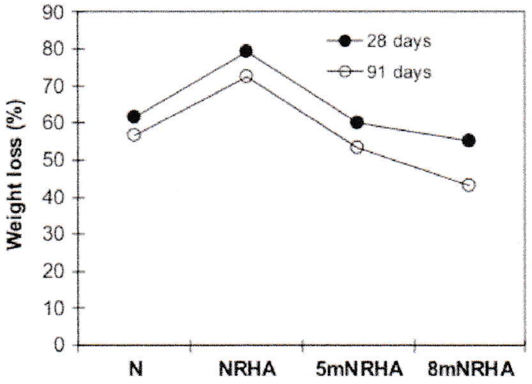
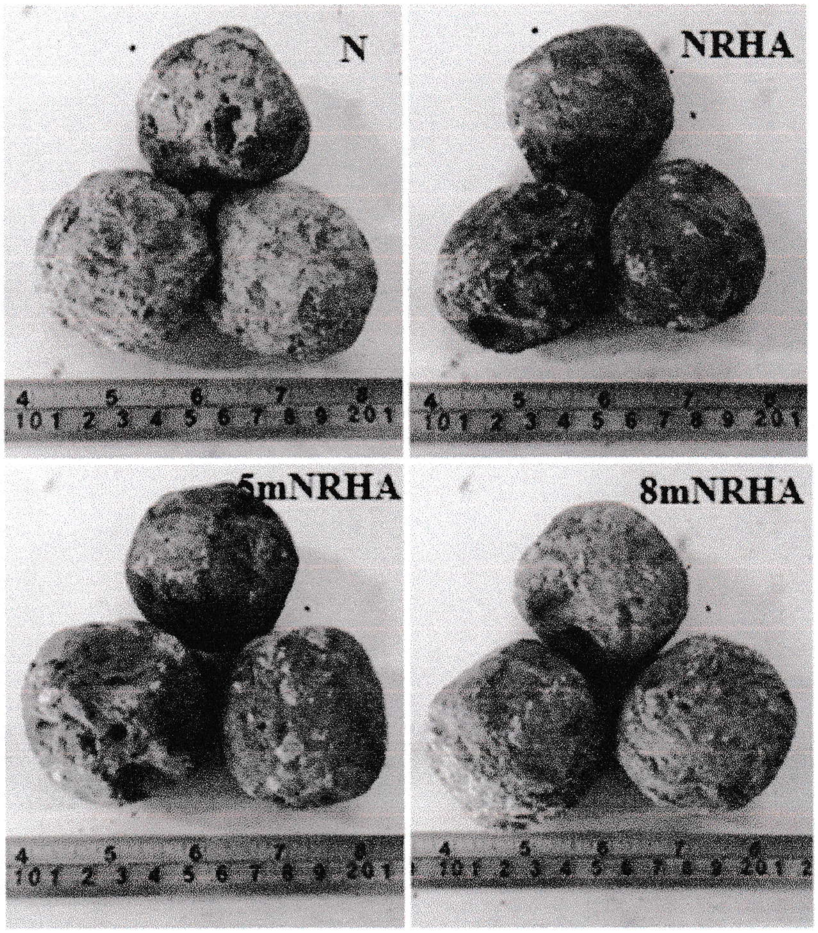


**Fig. 7** Weight loss after 1000 full rotations

1. NRHA is a viable alternative as cement replacement in concrete together with an optimized mixing duration to achieve a desired particle size.
2. Mixing NRHA with coarse aggregate for 8 min (8mNRHA) decreased SP demand, increased compressive strength, decreased permeability, and improved abrasion resistance due to the amorphous silica and the fine particle sizes of RHA, which provides excellent pozzolanic activity.
3. Abrasion resistance of NRHA concrete is strongly affected by compressive strength, modulus of elasticity, optimized mixing duration and curing age.
4. Abrasion resistance of 8mNRHA improved by 10.35 and 23.62% over control concrete at 28 and 91 days.
5. A polynomial regression was found as the best fit for data to determine relationship between abrasion resistance, compressive strength and modulus of elasticity of concrete.
6. The incorporation of 15% NRHA in concrete by optimization during the mixing process could be suitable for making conventional concrete, as well as for applications where abrasion resistance is an important parameter. In addition, using RHA as a partial replacement for cement contributes to a reduction of $CO_2$ emissions in the production of cement.

**Fig. 8** Shapes of specimens after 1000 rotations (91 days)



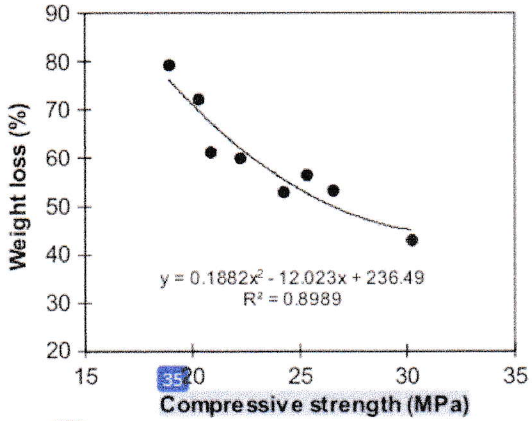


**Fig. 9** Relationship between weight loss and compressive strength

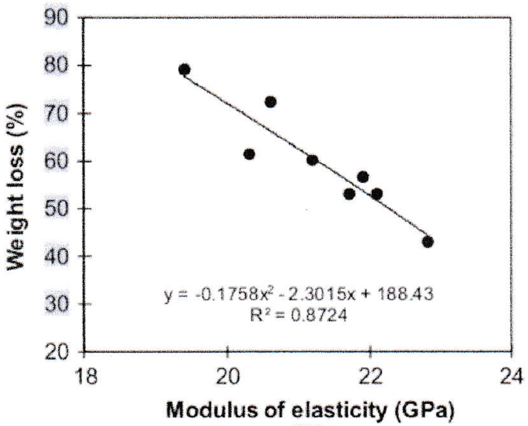


**Fig. 10** Relationship between weight loss and modulus of elasticity

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## Compliance with ethical standards

**Conflict of interest** The authors declare no conflict of interest.

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