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Strength Performance of Concrete using Rice Husk Ash as Supplementary Cementitious Materials (SCM)

Dahlia Patah*, Amry Dasar
Department of Civil Engineering, Universitas Sulawesi Barat, Majene, INDONESIA
Jl. Prof. Dr. Baharuddin Lopa, SH, Talumung, Majene
*Corresponding authors: dahliapatah@unsulbar.ac.id

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ABSTRACT Rice husk ash (RHA) is an industrial waste obtained from raw material that is processed into ash through the combustion process. It is a solid waste in fine powder form, which contains a large amount of silica and can promote RHA through combustion under certain conditions. Furthermore, it has a high pozzolanic activity due to a large amount of silica, which is a kind of supplementary cementitious material (SCM). According to ASTM C618, RHA has potential as sustainable material that meets the specification of the chemical configuration of pozzolan compound that can be used in cement products and concrete mixing. The use of RHA as SCMs in concrete construction contributes to sustainability and eco-material. Therefore, this study aims to evaluate the application of RHA as SCM on the strength base performance of concrete. The sample was directly collected from the rice field after the natural combusting process without additional treatment, controlled burning temperature, or time. RHA was used as an admixture for cement substitute and the mechanical characteristics were evaluated using a cylindrical concrete specimen made with 100-mm diameter and 200-mm height. After 24-hours, the concrete specimens were demolded and immediately immersed curing in fresh water with uncontrolled laboratory condition until the day of testing. The results showed that RHA with a replacement ratio of 7.5% obtained an optimum compressive strength of 40.65 MPa and 48.79 MPa at 28 and 91 days, respectively. The split tensile test also gave an optimum replacement ratio of RHA is 10% with 4.57 MPa at 28 days. These results provide good input on using RHA as SCM for concrete strength base performance and future sustainable material.

KEYWORDS RHA (Rice Husk Ash); SCM (Supplementary Cementitious Material); Concrete; Compressive Strength; Tensile Strength.

1 INTRODUCTION

Rice husk resembles a sheath that forms around the surface of rice grains during growth and is considered a by-product of the agricultural industry, which is categorized as solid waste material. After combusting, rich husk produces approximately 25% RHA of its initial weight with an estimated yield of 70 million tons annually. This product is an effective admixture for cement replacement because it contains a large amount of amorphous silica (Antiohos *et al.*, 2014). The RHA average particle size ranges from 5 to 10 μm and is appropriate for supplementary cementitious materials (SCM) (Sensale *et al.*, 2010). The potential of the finer particles to improve the concrete strength was also investigated by Mahmud *et al.* (1997). There is a need for RHA to meet the standard criteria for the chemical compound from pozzolan before being used in cement products and concrete mixing as specified in ASTM C618. The optimization of cementitious and pozzolanic by-products promoted sustainable expansion for the future of cement and construction industries (Papadakis *et al.*, 2002). This makes it necessary to investigate the reuse of RHA to reduce the number of waste materials, particularly from the agricultural industry. Previous investigations were carried out on the use of waste material as SCM in recent years due to the potential of RHA in construction materials (Nguyen *et al.*, 2011). The use of the remaining ash after combusting, namely RHA and fly ash (FA) as SCM in construction materials significantly increased its positive effect and applicability for sustainable material (Candra *et al.*, 2012, Patah *et al.*, 2020, Binti *et al*., 2020, and Patah *et al*., 2021). SCM is often used as mineral admixtures, however, it must meet the criteria of the accepted qualification before being incorporated into concrete mixing. The application of SCMs will improve their performance, mechanics, strength, unit weight, durability, permeability, and volumetric constancy in long term. Moreover, RHA is a type of mineral admixture and a part of SCM which is obtained as a by-product from the rice mill process. According to Raman *et al*. (2011), RHA is used as SCM to generate high-strength of concrete. Hesami *et al*., (2014) and Sugita *et al*., (1997) also reported that the minimum requirement for concrete compressive strength replacement with or without SCM in the mechanical parameter for normal concrete strength is approximately 15 MPa to 45 MPa at a density of 2400 kg/m^3. Meanwhile, RHA with the potential to generate high-strength concrete is necessary because mechanical properties such as concrete compressive strength are an important parameter of concrete structures for design and construction (Gastaldini *et al*., 2014). RHA is usually collected from rice fields with a natural combusting process after harvesting without additional treatment. Therefore, this study aims to provide information on the use of RHA as SCM for concrete strength performance. The data on the mechanical properties of concrete after partial replacement were also provided and the influence of RHA percentages was evaluated. The result indicated that RHA improved the mechanical performance of concrete compressive and tensile strength. The investigation of the effectiveness of RHA on the mechanical properties of concrete will help provide information to improve its application as future sustainable material.

2 MATERIAL AND METHODS

Table 1. Properties of material

Material	Type/Properties	Specific gravity (g/cm^3)	Specific surface area (m^2/g)
Cement	Portland Composite Cement (PCC)	3.145	382
RHA	Passing sieve No.50	2.24	87
Coarse Aggregate	Maximum 20 mm	2.56	-
Fine Aggregate	Passing sieve 5 mm	2.13	-
Water	Tap Water	1	

Table 2. Chemical properties of RHA (Houston *et al*., 1972)

Chemicals	%
Silicon Dioxide (SiO_3)	86.90 – 97. 30
Potassium Oxide (K_2O)	0.58 – 2.50
Sodium Oxide (Na_2O)	0.00 – 1.75
Calcium Oxide (CaO)	0.20 – 2.84
Magnesium Oxide (MgO)	0.12 – 1.96
Iron Oxide (Fe_2O_3)	0.00 – 0.54
Phosphorus Pentoxide (P_2O_5)	0.20 – 2.84
Sulphates (SO_3)	0.10 – 1.13
Chloros (Cl)	0.00 – 0.42

2.1 Material Used

This study used Portland Composite Cement (PCC) according to SNI 15-7064-2004 with the relative density, and specific surface area are 3145 kg/m^3 and 382 m^2/kg, respectively (Table 1). The PCC mixed in the concrete mixing was obtained from the Indonesian cement manufacturing industry. RHA can replace the amount of cement partially from 0-10% with 2.5% of interval addition by weight. RHA was produced through the natural combusting of rice husk without controlling the burning temperature and time.

The RHA that had been dried was sieved through No. 50 sieve as shown in Figure 1. The fine and coarse aggregate used were obtained from a local quarry in Majene. The river sand that passed through a 5-mm sieve was selected for use as a fine aggregate. Meanwhile, gravel that passed the 20-mm and held on a 5-mm sieve was selected as coarse aggregate. The classification standard for aggregate criteria was based on SNI 03-1968-1990. The range of chemical properties for RHA proposed by Houston *et al*. (1972) is shown in Table 2.

In this study, the cement was replaced with RHA by weight with a maximum replacement of 10%. The mix proportions were in line with the normal concrete mix design method.

Figure 1. Appearance of RHA. Specimen preparation

During the cement replacement, RHA was substituted at different percentages, namely 0%, 2.5%, 5%, 7.5%, and 10%. Mix proportions with 100% of PCC were used as a control specimen (RHA-0). The mix proportions of normal concrete are shown in Table 3, while RHA concrete is summarized in Table 4 and the mixing procedures are described in Figure 2. Saturated surface dry (SSD) condition of fine and coarse aggregates was used to ensure that the mixing process does not affect the water-to-binder ratio. The w/b ratio used is 0.40 and the consistency of the concrete was monitored by ensuring that the slump value is 60-180 mm as designed based on British Standard BS EN 12350-2. The concrete design strength was 25 MPa at 28 days.

Table 3. Normal concrete and design

Concrete mix	Cement	Fine aggregate	Coarse aggregate	Water
kg/cm^3	580	559	830	232
ratio	1	0.96	1.43	0.40

Table 4. Mix proportions of RHA

Term	RHA Percentage (%-weight of cement)	Water to binder ratio (by weight)	Cement (kg/m^3)	RHA (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
RHA-0	0%	0.4	580	-	559	830	232
RHA-2.5	2.5%	0.4	565.5	14.5	559	830	232
RHA-5	5%	0.4	551.7	28.3	559	830	232
RHA-7.5	7.5%	0.4	538.6	41.4	559	830	232
RHA-10	10%	0.4	526.1	53.9	559	830	232

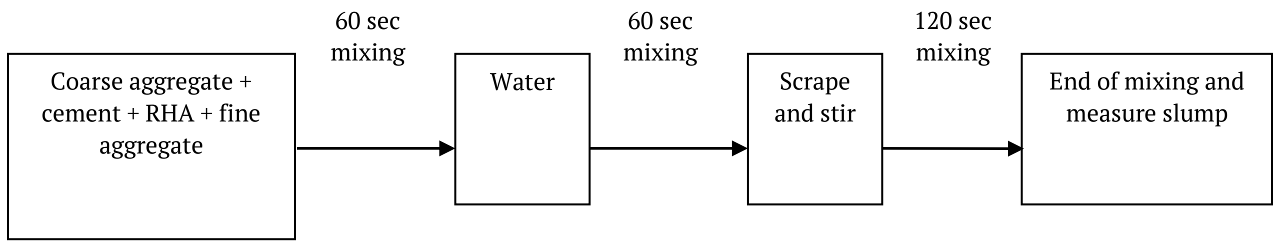

Figure 2. Mixing procedure of RHA

Table 5. Number of concrete specimens

Term	RHA Percentage	Number of specimens	
		Compressive strength	Split tensile strength
RHA-0	0%	12	6
RHA-2.5	2.5%	12	6
RHA-5	5%	12	6
RHA-7.5	7.5%	12	6
RHA-10	10%	12	6

2.2 Experimental Methods

The concrete specimens were cast in a cylindrical steel mold with a size of 200-mm high and 100-mm diameter using fresh water. A total of 60 specimens were made for compressive and 30 for split tensile strength evaluation as shown in Table 5. After 24-hours, the specimens were demolded and immediately cured by immersion in freshwater with uncontrolled laboratory conditions until the testing day, namely 7, 14, 28, and 91-days. The compression test was conducted on the concrete cylinder according to the method stated in SNI-1974-2011. Meanwhile, the split tensile strength test was carried out based on the procedures in SNI 03 2491 2002. The average compressive and split tensile strength from 3 specimens were determined for each concrete mixture.

3 RESULTS

3.1 Compressive Strength

The compression strength test was carried out to assess the influence of RHA as SCM on performance-based concrete. From the summary in Table 6, the concrete compressive strength increase with age in all cement replacement levels (CRL). At 7, 14, 28, and 91 days of compressive strength, RHA concrete passed a value of 25 MPa of strength design (Figure 3). This shows that RHA has potential for future sustainable materials. It was also discovered that the most favorable replacement ratio of rice husk ash was 7.5% at 28 and 91 days with compressive strength of 40.65 MPa and 48.79 MPa, respectively. Furthermore, only RHA with a replacement ratio of 7.5% at 91 days showed a significant increase in compressive strength. This is because of the longer days to complete hydration of cement at a later age or the smoother particle size of RHA (Mahmud *et al.*, 1997). The fine particle size of RHA is important because it affects the rate of reaction and helps achieve concrete strength. The modulus of elasticity (Ec) of concrete was determined with a calculation method based on SNI 2847:2013, which was according to the range of concrete weight from 1400 to 2560 kg/m^3. In this calculation, the 2 important parameters are the weight and compressive strength of concrete. The modulus of elasticity follows the trend of compressive strength as summarized in Table 6. This shows that the higher the compressive strength, the greater the elastic modulus.

Table 6. Compressive strength and modulus of elasticity of concrete at different age

Term	7 days		14 days		28 days		91 days	
	fc' (MPa)	Ec (MPa)	fc' (MPa)	Ec (MPa)	fc' (Mpa)	Ec (MPa)	fc' (MPa)	Ec (MPa)
RHA-0	29.26	25856.47	38.06	29940.91	39.33	30173.45	45.30	31156.54
RHA-2.5	29.17	26208.19	35.35	30302.79	38.78	29862.21	39.30	29963.53
RHA-5	32.54	26865.64	39.19	37460.49	39.98	27614.83	40.82	30954.69
RHA-7.5	31.05	26832.94	38.71	28639.59	40.65	30746.40	48.79	33444.68
RHA-10	29.40	26057.04	36.36	29368.49	40.02	29849.45	41.62	29002.84

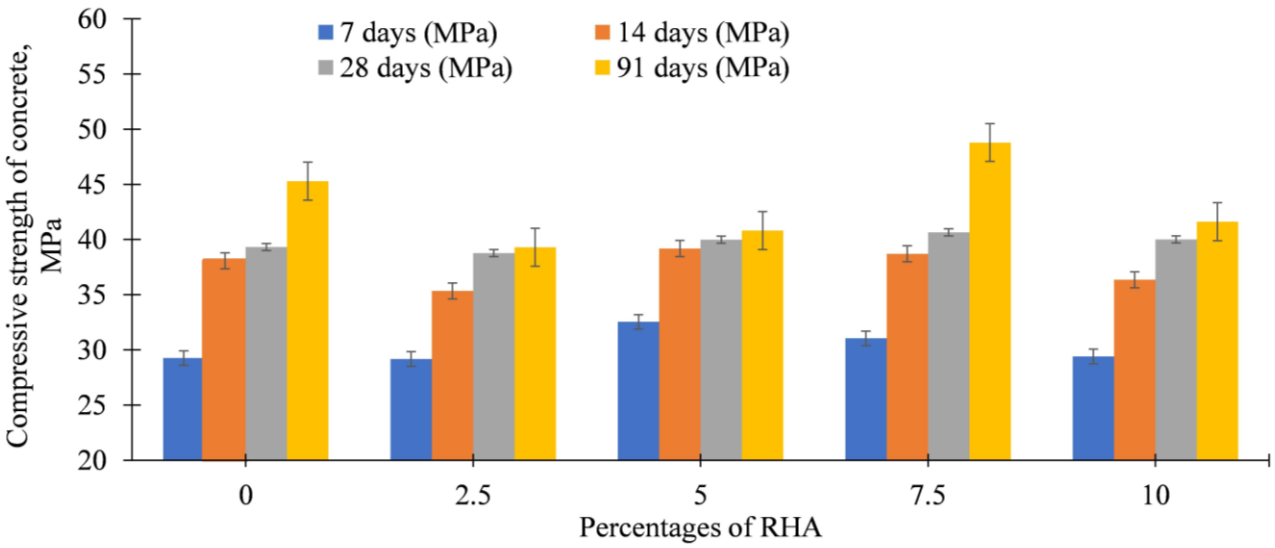

Figure 3. Compressive strength of concrete

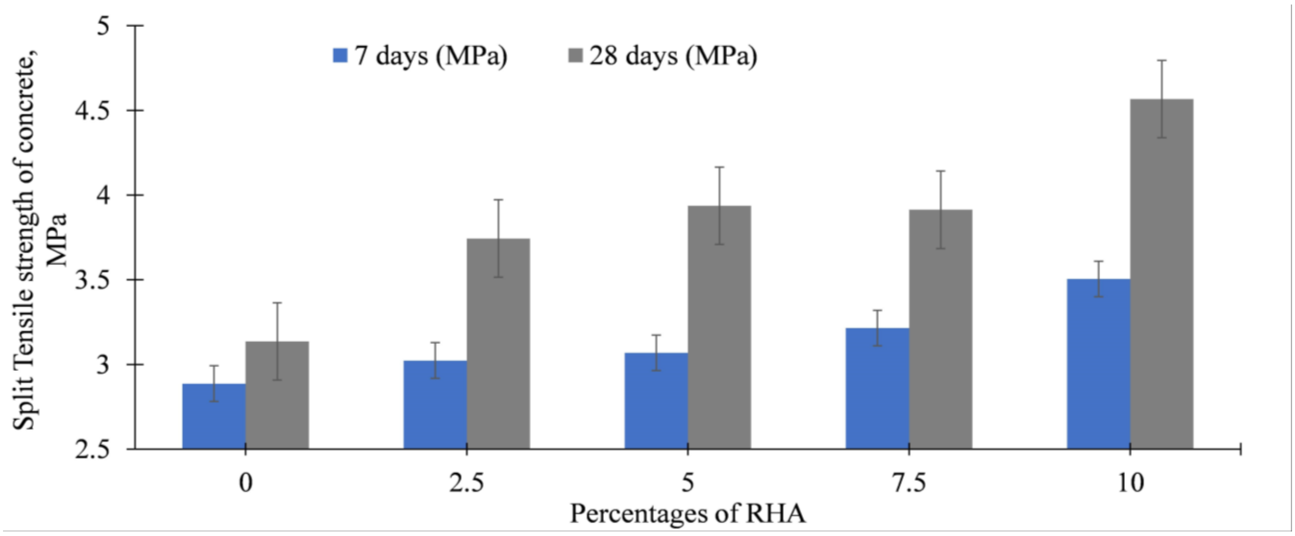

Figure 4. Split tensile strength of cylinder (7&28) days

3.2 Split Tensile Strength

Indirect methods are used to determine the tensile strength of concrete such as the split tensile test since there is difficulty in applying direct tension to specimens (Jittin *et al.*, 2021). There is a need to determine tensile strength because concrete is susceptible to tensile cracking. The split tensile strength at 7 and 28 days are shown in Figure 4. The concrete specimens with replacement of RHA showed a better split tensile strength which rises as the ratio increases compared to those without RHA (RHA-0) at 7 and 28 days. Additional calcium-silicate-hydrate (C-S-H), which increases the binder efficiency and the corresponding strength values at later days of curing was formed during the hydration of OPC. This is because the silica from the RHA reacts with calcium hydroxide liberated as a by-product. The strength is gained due to continuous hydration of OPC and the increase in pozzolanic reaction (Balendran *et al.*, 2000 and Ramasamy *et al.*, 2012). The split tensile strength of concrete with RHA was over 3 MPa in 7 and 28 days. The optimum replacement ratio of RHA was shown by 10% at 7 and 28 days with 3.51 MPa and 4.57 MPa, respectively. The mechanical properties were improved with the use of SCM, which enhances good particle packing effects (Jittin *et al.*, 2021).

4 DISCUSSION

The fine particle size of RHA contributed to the packing effect of the pores in the concrete, thereby increasing the compressive strength. At a 10% replacement ratio, the compressive strength was slightly reduced and the water demand was increased because RHA is more porous (Singh *et al.*, 2002). The compressive strength was also affected since the hydration process was not completed due to the higher absorption of 10% RHA. This slow hydration rate leads to a higher later age of compressive strength for RHA blended specimens (Chao-Lung *et al.*, 2011 and Givi *et al.*, 2010). This indicates the higher the cement replacement level (CRL), the more time need for compressive strength. Although the RHA used has particle size passed No. 50 sieve, the size of SCMs significantly affected the hydration process of the concrete (Ahsan *et al.*, 2018). Smaller particles react more quickly with water to advance the hydration process compared to larger particles. Split tensile strength best performance was obtained by 10% of replacement ratio RHA by weight of cement. According to Kaur *et al.* (2018), 10% of cement replacement levels (CRL) gave maximum value, but further replacement decreased the tensile strength. The percentage ratio of compressive strength to split tensile strength was summarized in Table 7. Figure 5 showed the split tensile strength of the concrete cylinder, which varies from 10 % to 12% of its compressive strength. The mechanical properties of concrete with RHA as SCM increase with age due to the physical effects of RHA. RHA reduced the number of the large pores and increased the probability of transforming the continuous pores into discontinuous ones. Therefore, all these mechanisms make the microstructure of the paste more homogeneous and denser.

Table 7. Percent ratio of compressive strength to split tensile strength test

Term	Ratio (%)	
	7 days	28 days
RHA-0	10.13	12.54
RHA-2.5	9.65	10.36
RHA-5	10.60	10.16
RHA-7.5	9.66	10.39
RHA-10	8.39	8.76

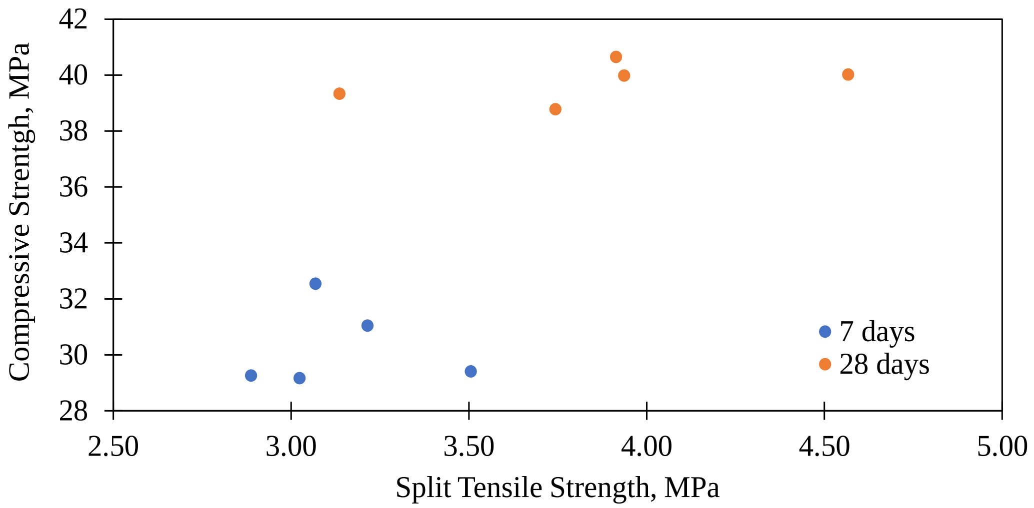

Figure 5. Split tensile strength of cylinder (7&28) days

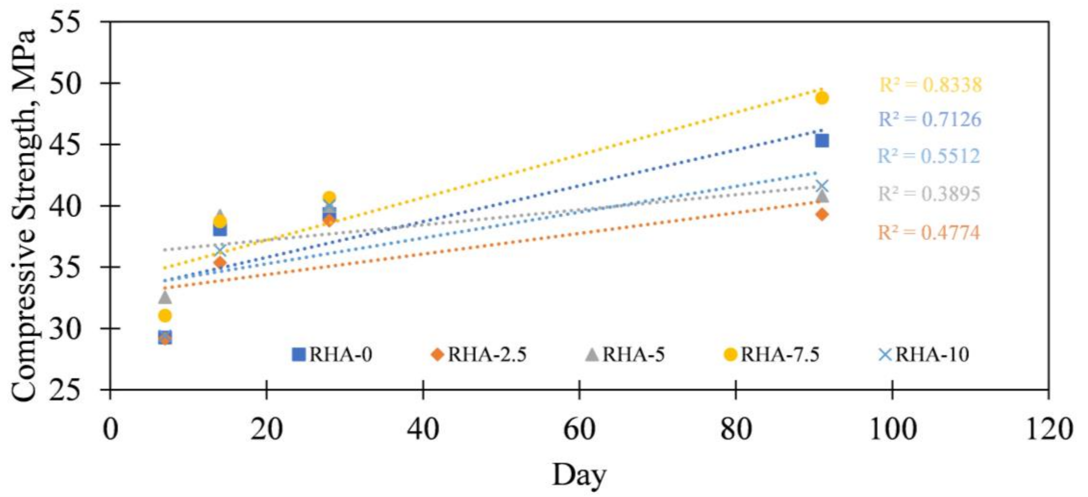

Figure 6. Relationship between days and compressive strength

The linear relationship between days of testing the compressive strength is shown in Figure 6. The R-square value obtained are as follows, 0.7126 RHA-0, 0.4774 RHA-2.5, 0.3895 RHA-5, 0.8338 RHA-7.5, and RHA-10 with 0.5512. Based on these results, RHA-7.5 showed that the relationship between age and compressive strength exhibited a consistent correspondence. The R-square value obtained from the linear regression is 0.8338 and the largest compared to another ratio. This indicated that RHA-7.5 is the optimum ratio for cement replacement by RHA.

5 CONCLUSION

The mechanical properties evaluation showed that RHA provided a positive contribution. The compressive strength rate of RHA concrete (RHA-7.5) achieved 48.79 MPa, while normal concrete (RHA-0) was 45.30 MPa. This showed that the application of RHA has potential for future sustainable construction materials. The split tensile strength of RHA-10 was 4.57 MPa, while normal concrete of RHA-0 had 3.14 MPa. This indicated that RHA has the potential to increase the mechanical properties and effectively support a sustainable environment.

For further study, the investigation on RHA obtained from natural combusting with a finer particle size which passed sieve No. 200 is recommended.

DISCLAIMER

The authors have no conflict of interest during the process of publishing this study.

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