Jordan Journal of Civil Engineering, Volume **19**, No. **2**, **2025**
DOI: https://doi.org/10.14525/JJCE.v19i2.12

Jordan Journal of Civil Engineering

Journal homepage: https://jjce.just.edu.jo

Utilization of Untreated Agricultural Waste Ashes Used as a Partial Fine Aggregate Substitution for Cement Mortar

***Hakas Prayuda* [1)*], *Fanny Monika* [1)], *Makhfudin Ashari* [1)], *Emil Adly* [1)], *Berkat Cipta Zega* [2)]**

[1)] *Department of Civil Engineering, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta. Bantul, Yogyakarta, Indonesia. * Corresponding Author. E-Mails: hakasprayuda@umy.ac.id, fanny.monika.2007@ft.umy.ac.id, makhfudin.a.ft18@mail.umy.ac.id, emil@umy.ac.id.*

[2)] *Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Surabaya. Surabaya, East Java, Indonesia. E-Mail: berkatzega@unesa.ac.id*

ARTICLE INFO

Article History:
Received: 21/10/2024
Accepted: 30/3/2025

ABSTRACT

In various countries, construction materials have immensely increased due to rapid urbanization, leading to extremely high demand for natural resources. In general, many countries rely on concrete as their main construction material. Therefore, the demand for natural resources continues to rise, such as cement, fine aggregate, and coarse aggregate. In addition, the agricultural sector works to sustain the economy and provide the essential needs of communities. This sector produces various wastes that have not been sufficiently utilized. This study attempted to utilize agricultural wastes as substitutes for fine aggregate in cement mortar. The agricultural wastes used in this study consist of the sugarcane farm (bagasse ash), the rice farm (rice husk ash), and the corn farm (cob corn ash). Utilization of these wastes aims to reduce the exploitation of sand as fine aggregate for the production of mortar and to increase the amount of agricultural wastes to be sufficiently utilized. Experiments on the laboratory scale were conducted to measure the fresh and hardened properties of cement mortar. Fresh properties were evaluated using the slump flow test, while hardened properties were evaluated by compressive strength, porosity, water absorption, and mass loss. In addition, non-destructive tests, including rebound hammer and ultrasonic pulse velocity tests, were conducted. The compressive strength results decreased as the amount of agricultural waste increased during early ages. However, the compressive strength increased significantly when the amount of agricultural waste increased at 28 days as a curing period. This investigation indicates that introducing agricultural wastes for additional mortar materials can improve its compressive strength and other properties. However, appropriate mix proportions are required to produce high-performance mortar.

Keywords: Cement mortar, Bagasse ash, Rice husk ash, Cob corn ash, Engineering properties, Cementitious materials.

INTRODUCTION

Increases in urbanization and industrialization lead to a high demand for infrastructure. Concrete and mortar have recently become the most utilized construction materials worldwide. Concrete is typically composed of cement, fine aggregate, coarse aggregate, water, and additional additives/admixtures, depending on the construction requirements. The production of concrete and mortar as construction materials is predicted to increase significantly until 2050, particularly in developing countries, such as China, India, Indonesia, Thailand, and other countries in Asia, Africa, and the Middle East (Schneider et al., 2011; Imbabi et al., 2012). However, large concrete production significantly contributes to rising pollution, especially by causing the release of carbon dioxide into the atmosphere. Each stage of the life cycle of concrete or mortar begins with the acquisition of raw materials, concrete plans, mixing processes, transportation to the site, construction stage, curing stage, service life, and demolition stage, noting that concrete construction always has a substantial influence on the environment (Jain et al., 2023; Monika et al., 2022; Sanal, 2018). According to several studies, each stage of concrete manufacture and demolition results in gas emission release of up to 8% annually (Wesseling & Vooren., 2017; Danis et al., 2019). In terms of constituent materials, the significant sources of carbon dioxide in concrete and mortar manufacturing come from the production of cement and the exploitation of natural resources for fine and coarse aggregates (Monika et al., 2022).

The utilization of fine and coarse aggregates for concrete manufacture continues to consume natural resources. It is predicted that aggregate consumption for concrete production will exceed 500 billion tons by 2100 or 30 billion tons annually (Bendixen et al., 2021; Pok et al., 2021). Most of the aggregates used in the production of concrete and mortar are sourced from river extraction, which can result in ecological changes and floods (Saleh et al., 2022). In addition, several countries, including Singapore, the United States, and France, have limited natural resources. Therefore, they must import aggregates for the construction sector from other countries (Gavriletea, 2017). Because of these limitations, efficient and sustainable management is required to preserve the viability of environmentally friendly infrastructure development. In addition, some innovations are necessary for environmentally friendly materials to reduce the consumption of natural resources, such as sand, stone, and gravel. Several improvements based on previous research results have also been identified, such as the use of recycled concrete construction waste for supplementary aggregate (Xiao et al., 2012; Tam et al., 2018; Guo et al., 2018) and the utilization of industrial wastes, such as fly ash, bottom ash, and blast furnace slag (Sancheti et al., 2020; Thomas & Thomas, 2022; Ghunimat et al., 2023; Sambangi & Eluru, 2022; Gooi et al., 2020). Nonetheless, several alternative materials have not been utilized to their fullest potential.

The agriculture and plantation industries are some of the most important economic pillars in some countries, particularly in developing countries. However, it cannot be denied that this industry also harms the environment, since it generates unmanageable biomass wastes. In some countries such as Brazil, India, China, Indonesia, and other developing countries in south Asia and south-east Asia, agricultural wastes, such as rice, corn, and sugarcane farms, are growing rapidly (Pode, 2016; Bhattacharya et al., 2005). It is reported that farmers, particularly in rural areas of developing countries, frequently dispose of agricultural waste by burning it in the open field (Charitha et al., 2021; Athira et al., 2019). Burning agricultural waste in an open field is a common practice that causes serious land and air pollution. In Asia, waste burnt in open fields accounts for up to 34% of the total biomass burnt yearly. India and China are significant contributors to open-field burning for agricultural wastes (Rithuparna et al., 2021; Streets et al., 2003). In several rural areas of Indonesia, similar methods for disposing of agricultural wastes can be found. The incinerated waste has not been effectively handled and has been allowed to pollute agricultural areas, endangering plants and farmland.

Some studies indicated that the combustion products of agricultural wastes have a pozzolanic chemical composition, allowing for their use as materials as concrete substitutes to be highly feasible. It has been found that rice husk ash waste contains up to 90.21% SiO_2 and 1.27% CaO (Jung et al., 2018), bagasse ash waste contains 64.88% SiO_2 and 10.69% CaO (Chusilp et al., 2009), and corn cob ash waste has 66.38% SiO_2 and 11.5% CaO (Adesanya & Raheem, 2009). The results of these studies indicated that some wastes from the agro-industry have a substantial potential for usage as concrete and mortar materials. To produce quality ash with optimal pozzolan content, waste must be burnt to a temperature between 600 °C and 1100 °C for rice husk ash, cob corn ash, bagasse ash, and other types of agro-industry wastes (Cordeiro et al., 2009; Lima & Cordeiro, 2021; Della et al., 2022; Muthadhi & Kothandaraman, 2010). Meanwhile, the temperature of waste produced by burning in an open field is not measured. Therefore, utilizing this waste necessitates an advanced stage and defective equipment, particularly for application in rural areas of Indonesia. Therefore, this study tried to utilize agricultural wastes as fine aggregate substitutes.

This research employs agricultural wastes in the form of rice husk ash, bagasse ash, and corn cob ash as substitutes for sand in the production of mortar. The waste utilized results from open field burning in some rural areas in Indonesia. Several research results related to these agricultural wastes, notably in Indonesia, have also been uncovered, such as rice husk ash (Djamaluddin et al., 2018; Wahyuni et al., 2014; Prayuda et al., 2020), bagasse ash (Raharjo et al., 2017; Saleh et al., 2019; Joshaghani & Moeini, 2018; Jimenes-Quero et al., 2013), and corn cob ash (Abdullah et al., 2021; Mildawati et al., 2022; Aswin et al., 2021; Arici et al., 2021). These results show that wastes from the agro-industry can be used as substitute materials in concrete and mortar construction. However, previous research has not compared the effects of various agro-industry wastes in Indonesia. In addition, the method of treating waste prior to its usage as a construction material for concrete or mortar is not systematically detailed. Therefore, this study aims to generate a more systematic and simple proportion that can be utilized by the general community, particularly in rural areas of Indonesia. Through this research, it is expected that agricultural and plantation wastes will be more effectively utilized as construction materials.

Scope of the Study

This study employs three different types of agricultural waste, including corn cob ash (CCA), rice husk ash (RHA), and bagasse ash (BA). Each agriculture waste in this study is used as a replacement material for fine aggregate. The properties of the constituent materials, such as cement, agricultural waste, and fine aggregate, are examined. Figure (1) shows the experimental outline and scope of the investigation of this study.

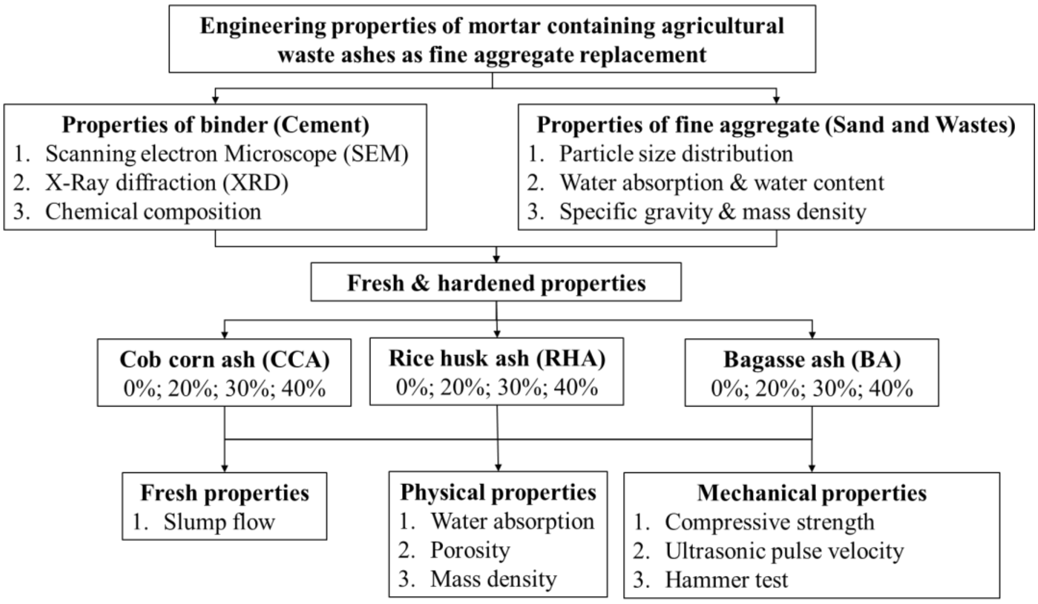


Figure (1): Experimental outline and scope of the study

Micro-structure test was carried out to investigate the binder properties by using a scanning electron microscope (SEM) and X-ray diffraction (XRD), while fine aggregate properties (agricultural waste and sand) consisting of specific gravity, mass density, water content, water absorption, particle size distribution, and fineness modulus were also investigated. The variation of fine aggregate replacement consists of 0%, 20%, 30%, and 40% by weight of sand for all types of waste. This study examined the engineering properties of mortar by evaluating its fresh, physical, and mechanical properties. The fresh properties consisted of a slump flow test to determine the workability and water consumption for producing mortar with various amounts of waste as fine aggregate replacement. The investigation of physical properties in this study consists of porosity, water absorption, and mass loss tests. The compressive strength investigation in this study also considers the ages of specimens of 3, 7, and 28 days. In addition, ultrasonic pulse velocity (UPV) and hammer tests were conducted on the specimens at 28 days.

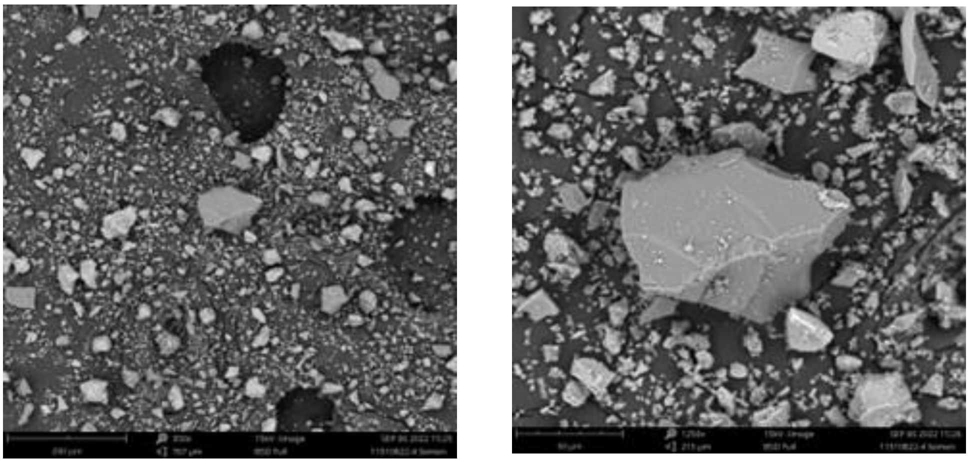
EXPERIMENTAL PROGRAM

Raw Materials

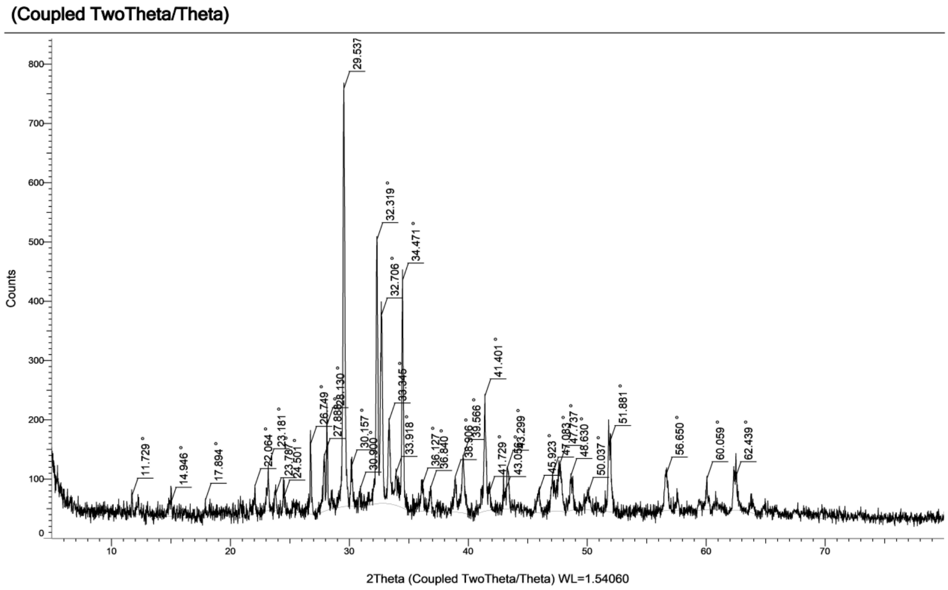
The constituent materials used in this study consisted of binders, water, and fine aggregates. The binder used is Portland pozzolan cement (PPC) according to ASTM C595 (ASTM International, 2021). The characteristics of the binder are evaluated by analyzing its chemical composition and micro-structure composition using a scanning electron microscope (SEM) and X-ray diffraction (XRD). The chemical composition of the utilized Portland pozzolan cement is shown in Table 1, and the results of the SEM and XRD tests are shown in Figure (2). The results of micro-structure analysis in this cement show that the intensity values of calcium (Ca), silicon (Si), and (O) elements are very significant in a binder containing cement. This demonstrates the critical nature of cement in the mixture, because these elements contribute to the hydration process.

Table 1. Chemical composition of binder (Portland pozzolan cement)

CC	SiO_2	Al_2O_3	FE_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LoI
Amount	32.59	7.51	2.05	47.83	1.61	2.90	3.62	1.80	0.09



(a) Scanning electron microscope (SEM) (350X and 1250X)



(b) X-ray diffraction (XRD)

Figure (2): Results of SEM and XRD for Portland pozzolan cement

This study utilized river sand from Kulon Progo in Yogyakarta, Indonesia, as the fine aggregate. In addition, three types of agricultural waste (CCA, RHA, & BA) produced from open-field burning in farmlands in Yogyakarta, Indonesia, are utilized in this study. The condition of the fine aggregates used to manufacture mortar is shown in Figure (3). The physical and mechanical properties of each agricultural waste and sand are inspected. The test properties for fine aggregates included the examination of specific gravity, water content, water absorption, mass density, particle size distribution, and fineness modulus. The results of the mechanical properties of each waste and sand are shown in Table 2.

According to Table 2, the specific gravity of sand is higher than that of all agricultural wastes. This was determined by comparing the mechanical parameters of agricultural wastes and sand. The important point of this investigation is that the water content and absorption indicate that all agricultural wastes have higher values than sand. This indicates that more water will be required by substituting waste for fine aggregate. This is because agricultural wastes can absorb more water than river sand. In addition, it is observed that the mass density of agricultural wastes is significantly lower than that of river sand, which makes it possible to construct a lightweight mortar when utilizing waste materials as replacements for fine aggregate. In addition, Figure (4) shows the particle size distribution for river sand and all agricultural wastes.

Table 2. Physical properties of sand (fine aggregate) and agricultural wastes

Properties	Unit	Sand	CCA	RHA	BA
Specific gravity	-	2.37	1.17	1.98	2.13
Water content	%	1.34	10.89	11.35	9.89
Water absorption	%	2.10	25.25	26.45	23.12
Mass density	g/cm^3	1.89	0.80	0.72	0.93
Fineness modulus	-	2.43	1.29	1.01	2.07

(a) River sand

(b) Corn cob ash

(c) Rice husk ash

(d) Bagasse ash

Figure (3): Fine aggregate and agricultural wastes used in this work

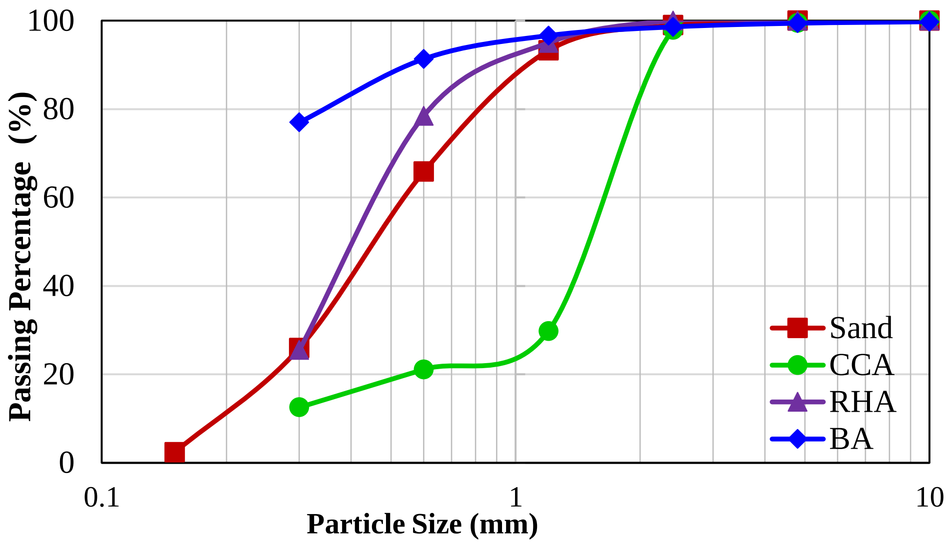


Figure (4): Particle size distribution of sand and agricultural wastes (CCA, RHA, & BA)

Mix Proportions

Table 3 shows the mix proportions used to produce a 5.0 × 5.0 × 5.0 cm^3 specimen. Each waste uses a variation of sand replacement of 20%, 30%, and 40% of the total weight of fine aggregate. The determination of a variation of up to 40% takes into account the simplicity of manufacturing and the duration of the hardening process of the mortar, which becomes longer as the amount of waste utilized is increased. In addition, this investigation used a water-to-binder ratio of 0.55 for all variants. The determination of the water-to-binder ratio of 0.55 is based on an analysis of normal mortar. The water needed for water-to-binder ratio of 0.55 achieves the slump flow criteria required for the workability of fresh mortar. The determination of water-to-binder ratio of 0.55 is based on a trial and error experiment of normal mortar. It should be noted that the specimen with ID 100S is a control mortar (normal mortar) specimen.

Table 3. Mix proportions for one specimen (5.0 × 5.0 × 5.0 cm^3) in kg

Specimen ID	Cement	Water	Sand	CCA	RHA	BA
100S (controlled)	0.0687	0.0378	0.206	-	-	-
80S20CCA	0.0687	0.0378	0.187	0.018	-	-
70S30CCA	0.0687	0.0378	0.178	0.281	-	-
60S40CCA	0.0687	0.0378	0.169	0.375	-	-
80S20RHA	0.0687	0.0378	0.187	-	0.018	-
70S30RHA	0.0687	0.0378	0.178	-	0.281	-
60S40RHA	0.0687	0.0378	0.169	-	0.375	-
80S20BA	0.0687	0.0378	0.187	-	-	0.018
70S30BA	0.0687	0.0378	0.178	-	-	0.281
60S40BA	0.0687	0.0378	0.169	-	-	0.375

Experimental Methods

The main components of the investigations conducted were evaluating fresh and hardening properties. For the investigation of fresh properties, flow table tests are conducted for all variations. This experiment is designed to determine the workability of fresh mortar. The flow table test was conducted following ASTM C230 (ASTM International, 2021). After conducting the flow table test, all fresh mortars are poured into the molds and removed 24 hours later. After seven days of water curing, all specimens were placed in dried curing at room temperature. The compressive strength test was conducted on mortar aged 3, 7, and 28 days. The test size of the specimens for compressive strength of 5.0 × 5.0 × 5.0 cm^3 refers to ASTM C109 (ASTM International, 2021).

In addition, the assessment of water absorption, mass density, and mass loss of mortar are investigated. The water absorption test for mortar refers to ASTM C1403 (ASTM International, 2022), while the porosity and mass loss tests on mortar refer to ASTM D6023 (ASTM International, 2016). Besides, this investigation carried out non-destructive tests in the form of UPV and hammer tests on mortar specimens that were 28 days old. This NDT study aims to compare the results of the non-destructive test and the compressive strength. The UPV test refers to ASTM C597 (ASTM International, 2016), while the hammer test refers to ASTM C805 (ASTM International, 2018).

RESULTS AND DISCUSSION

Fresh Properties (Flow Table Test)

In the manufacturing process of mortar and concrete, one of the critical aspects is the fresh characteristics. This is because of the feasibility of determining fresh performance and easy processing of fresh concrete by studying its fresh properties. Figure (5) shows the results of fresh properties for all specimens utilized. To compare the results of fresh and hardened characteristics, all specimens employ the same water-to-binder ratio of 0.55. Fresh mortar, without waste constituent materials, has produced a slump flow of 14.55 cm. A significant reduction in slump flow values was seen in specimens using agricultural wastes as fine aggregate replacements, particularly in the 40% variant of waste substitution, which included CCA, RHA, and BA wastes. The reduction in slump flow value signifies that an increased quantity of waste complicates the management of fresh mortar prior to its placement into the molds. This also demonstrates that the 40% variant necessitates a faster processing time, because if the casting process takes too long, the fresh mortar can evaporate before it is poured into the molds.

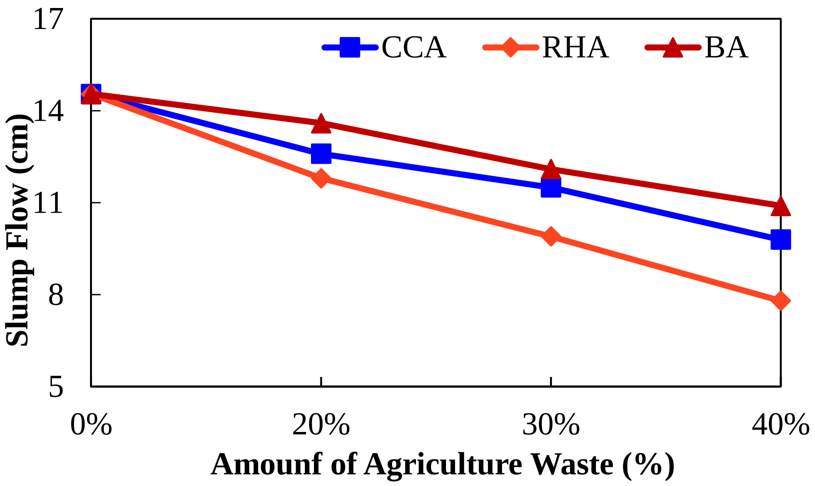


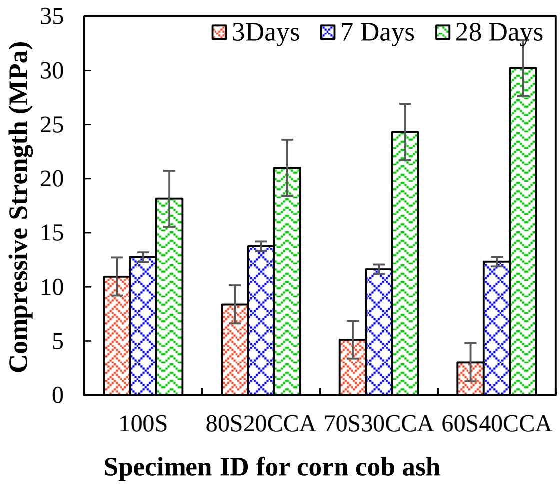
Figure (5): Slump flow of fresh mortar with agriculture wastes *versus* sand replacement ratio

The decreased slump flow value due to an escalation in agricultural waste indicates that a rise in waste necessitates an increase in water demand. This aims to maintain the workability of fresh mortar to facilitate the casting process. Further investigation is needed regarding the effect of the water-to-binder ratio for more than 40% of waste. In addition, Figure (5) shows that bagasse ash waste results in the lowest reduction in slump flow, rice husk ash results in the highest reduction in slump flow, and corn cob ash results in slump flow between the other two wastes. It can be concluded that different types of waste produce different patterns of fresh properties. RHA waste produces a lower slump flow (higher decrease), because this waste has a relatively high capacity to absorb water, as demonstrated I Table 2, where RHA has the largest water absorption compared to CCA and BA. Therefore, the waste absorbs the consumed water, resulting in a severe decrease in workability (slump flow). In contrast, BA waste has the lowest water absorption ability. The water absorbed by BA waste is not significantly larger than the water absorbed by CCA and RHA wastes. Previous studies also demonstrated comparable results, indicating that the utilization of RHA leads to significant decreases in slump flow compared to normal mortar (Prayuda et al., 2023).

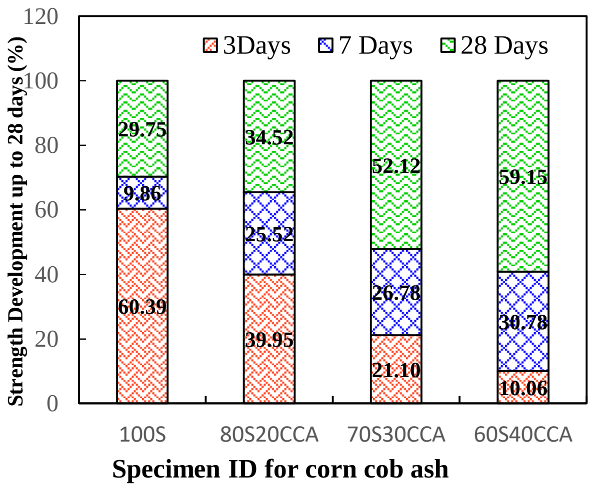
Compressive Strength

The obtained compressive strength is the average of five test specimens for each variant. Figure (6) shows the compressive strength results for mortar with corn cob ash as an additional material. Figure (7) shows the results of the compressive strength of mortar with the addition of rice husk ash, while Figure (8) shows the compressive strength of mortar with the addition of bagasse ash. The test results on all variants of agricultural wastes indicate that, as the age of the concrete increases, the resulting compressive strength also increases. This is because the hardening process causes mortar on all test objects to get harder over time.

Figure (9a) shows that the compressive strength of mortar at 3 days of age reduced dramatically with increasing the amount of agricultural waste as a replacement for fine aggregate. In mortar with 40% CCA, RHA, and BA wastes, the compressive strength decreased by more than 50% at mortar with the age of 3 days. This significant decrease in compressive strength must be considered when utilizing these wastes as construction materials, particularly for structural elements. In addition, considering compressive strength of mortar decreases as it ages; particular precautions must be taken during the construction stage. This results in a longer curing or waiting period before the next construction phase. The waste material, which contains pozzolans, but does not react while the mortar is still wet, is responsible for lower compressive strength at an early age. Therefore, mortar is still weak at an early age. For mortar aged 28 days, the compressive strength has increased dramatically alongside the increase in agricultural waste, as measured with specimens using CCA, RHA, and BA. Figure (9b) shows the correlation between the compressive strength of mortar and the amount of agricultural waste after 28 days. The mortar at this age is in a dry condition and has almost entirely hardened, increasing its compressive strength. In addition, the pozzolan component produced increases due to the large amount of waste utilized. This waste material does not react or harden when mixed with water, but does so when mortar dries. Therefore, the compressive strength of mortar increased significantly after 28 days.

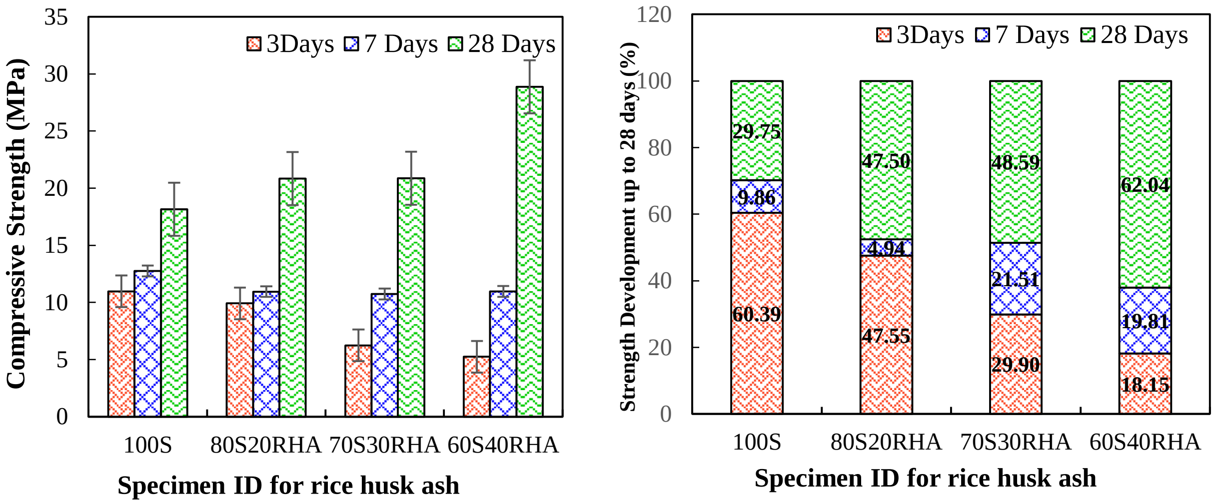


(a) Compressive strength with different ages



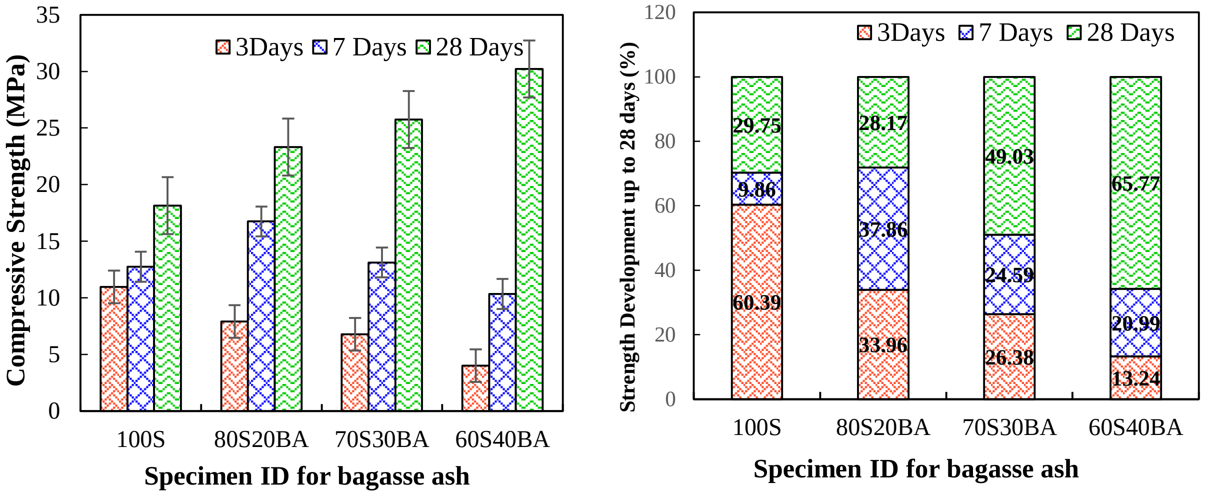
(b) Strength development

Figure (6): Compressive strength development of hardened mortar with corn cob ash



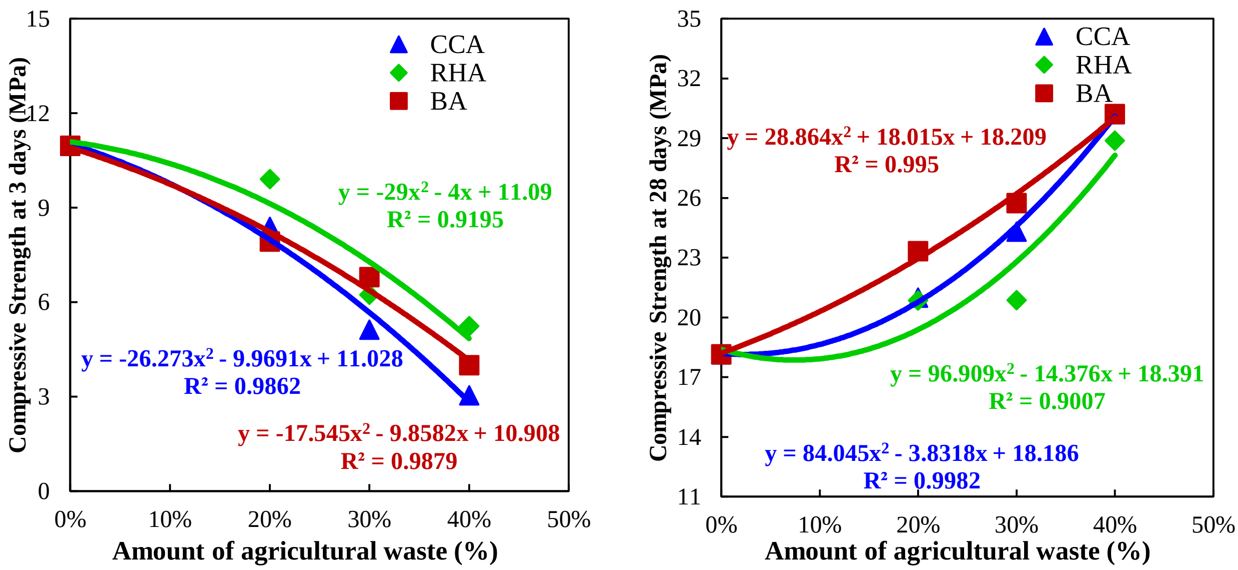
(a) Compressive strength with different ages (b) Strength development

Figure (7): Compressive strength development of hardened mortar with rice husk ash



(a) Compressive strength with different ages (b) Strength development

Figure (8): Compressive strength development of hardened mortar with bagasse ash



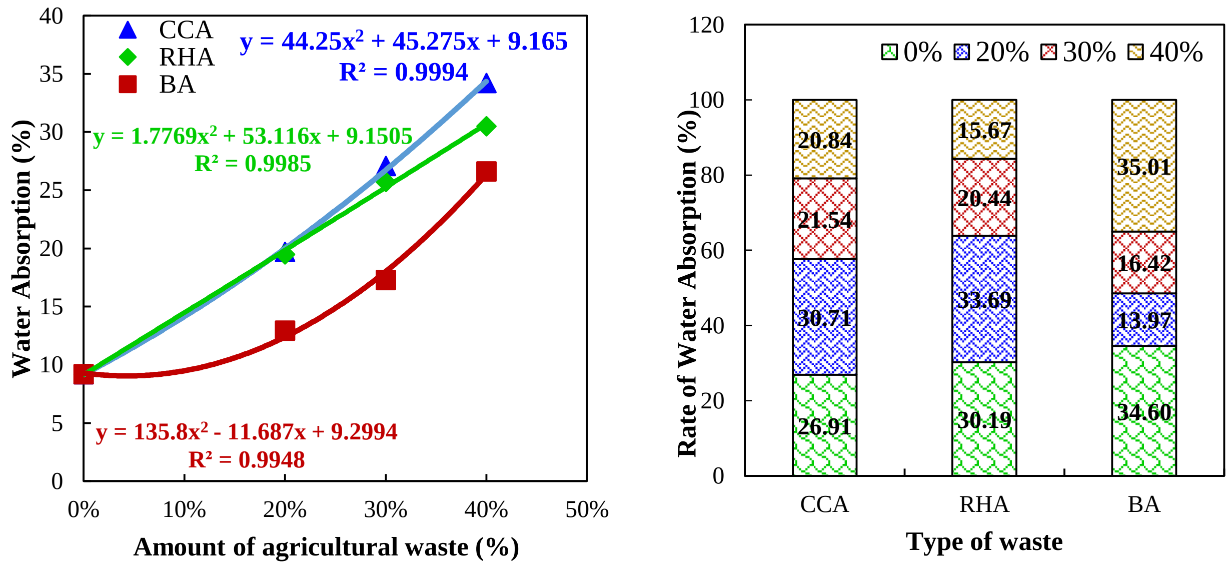
(a) At 3 days (b) At 28 days

Figure (9): Relationship between the amount of waste and compressive strength

Comparing the compressive strength data between 3 days and 28 days shows a difference in the hardening mechanism between conventional mortar and mortar containing agricultural wastes in replacement of sand. In terms of its strength development, normal mortar undergoes significant hardening at the early age of 3 days, comparable to 60% of the overall strength achieved after 28 days of curing. However, with increasing waste content in the mortar, the strength development for 3 days decreased significantly. At a waste variation of 40%, the normal mortar (100S) strength development at 28 days does not exceed 20% of the overall compressive strength. However, strength development in a mortar containing 40% waste increased drastically when water curing was completed. In a normal mortar, the hardening process happens mainly at the early age of the concrete during the water curing process, and the increase in compressive strength has developed gradually up to the age of 28 days. In contrast, in a mortar containing agricultural wastes (CCA, RHA, BA), strength increase does not proceed effectively at the early age of the mortar, particularly in the waste type containing a high amount of waste. This is due to the effect of curing and the state of the mortar in moist conditions, which weakens the mortar. However, compressive strength improved dramatically after water curing was completed, particularly in specimens with high waste content.

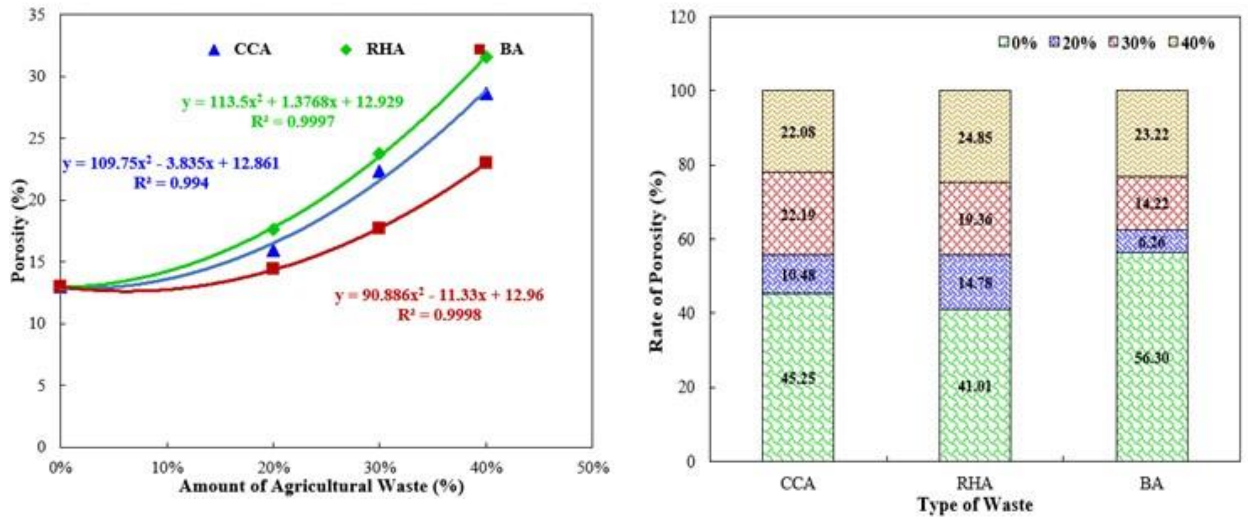
Water Absorption and Porosity

In addition to compressive strength, water absorption and porosity of mortar were also evaluated. The specimens were 28 days old. Figure (10) shows the results of the water absorption test conducted on all specimens aged 28 days, while Figure (11) shows the results of the porosity test. This experiment demonstrates that water absorption and porosity increase as waste content increases.



(a) Water absorption (b) Rate of water absorption

Figure (10): Relationship between the amount of agricultural waste and water absorption



(a) Porosity (b) Rate of porosity

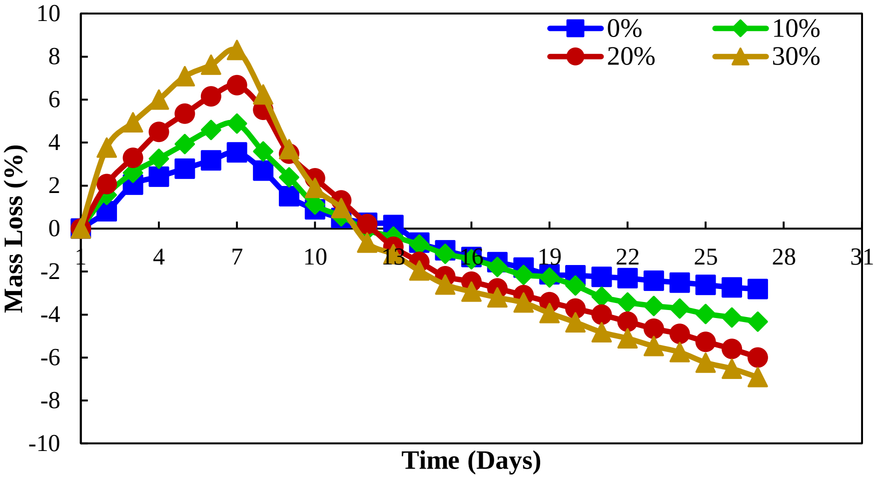
Figure (11): Relationship between the amount of agricultural waste and porosity

The maximum water absorption was seen in mortar containing 40% waste variant, particularly CCA and RHA. CCA and RHA wastes are more capable of absorbing water than BA waste. Because the mortar is dry after 28 days, these two wastes are able to absorb significantly more water than BA waste. Moreover, based on the water absorption rate, it is evident that each waste does not absorb water differently. Between CCA, RHA, and BA, the water absorption rate is nearly identical for each variant. The investigation results on the porosity of hardened mortar indicate that the porosity increases as the amount of agricultural waste increases (Prayuda et al., 2023; Vishavkarma et al., 2021). This is due to the influence of the amount of waste used. Therefore, the ability to absorb water also increases as the amount of waste used increases. In terms of water absorption and porosity, BA waste possesses superior qualities.

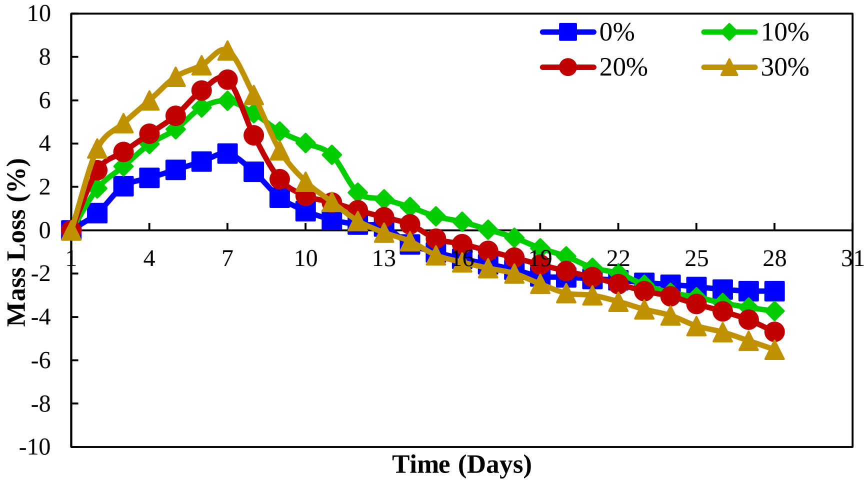
Mass Loss and Mass Density

The purpose of mass loss measurement is to evaluate weight changes and the potential for weight loss due to the addition of material in the form of agricultural waste. Figure (12) shows the results of mass loss measurements for all specimens.

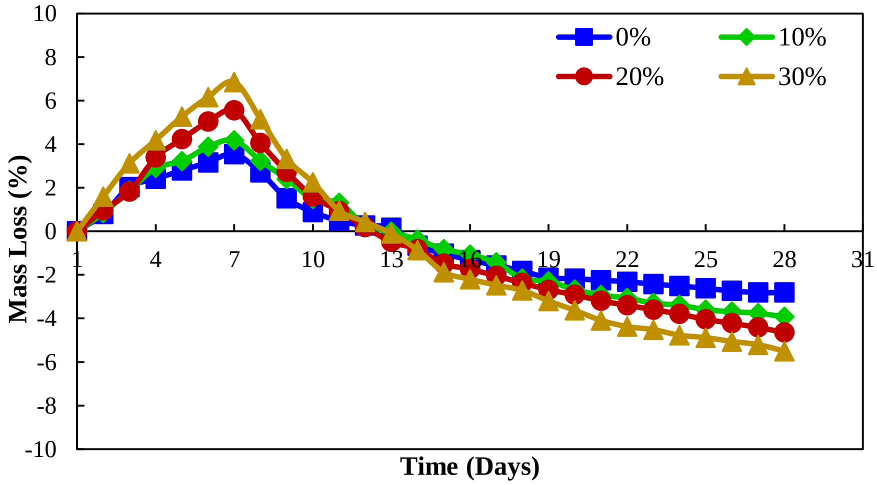
During the water curing process, mortar with the highest waste content (40%) gains more mass than mortar with the lowest waste content. This occurs because of the influence of the ability of mortar to absorb water during the curing process, which employs water curing. Therefore, the mass of mortar increases, which may be related to the amount of water that the mortar can absorb. The more the waste utilized, the higher the capacity to absorb water and the higher the weight gain. This tendency applies to all waste types, with the variant of 40% waste resulting in an increase in mass throughout the curing process. Normal mortar has the smallest increase in mass compared to other variants. After completion of the curing phase, mortar is placed indoors using dried curing. During this process, mortar dries, and the amount of water in the mortar reduces, resulting in a significant drop in the mass of mortar, as shown in Figure (12). Specimens with a high waste content experience more mass loss than those with a low waste content. At 28 days, mortars containing CCA, RHA, and BA that varied by 40% experienced the largest mass loss. Significant mass loss in specimens containing 40% waste is obviously determined by the amount of waste utilized and the capacity to absorb water. The higher the absorption capacity, the faster it will dry. Therefore, mortar with a larger amount of waste produces a higher mass loss.



(a) Corn cob ash mortar



(b) Rice husk ash mortar



(c) Bagasse ash mortar

Figure (12): Mass loss of hardened mortar up to 28 days

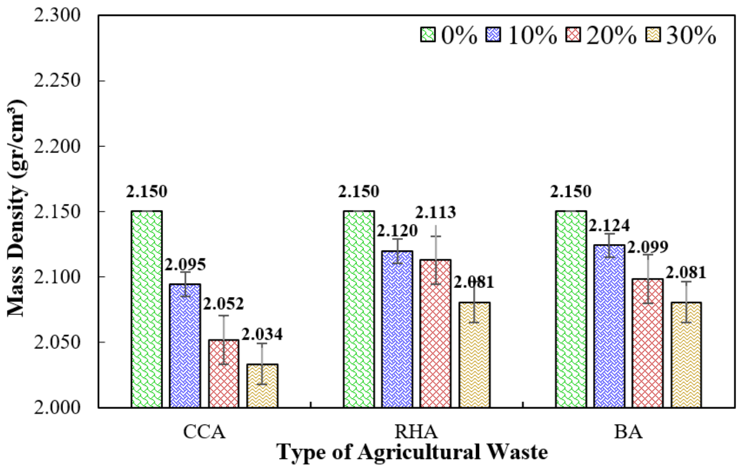
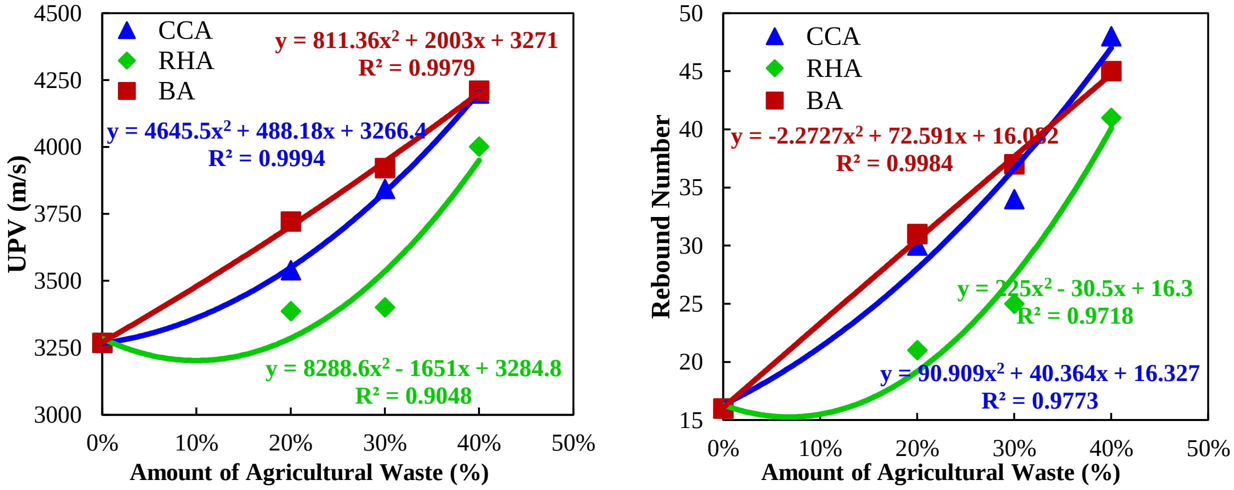


Figure (13): Mass density of mortar with agriculture wastes *versus* sand replacement

Figure (13) shows the results of mass density measurements for all specimen variants. The specimens used for measurements were 28 days old. It can be seen from these observations that as the amount of waste increases, the resulting mass density decreases. It can be concluded that as waste increases, the hardened mortar becomes lighter. Obviously, this has a beneficial effect on construction materials, allowing them to produce lightweight materials and comparable quality to conventional mortar. Mortar made from CCA waste is always the lightest once it has been hardened (Prayuda et al., 2023; Vishavkarma et al., 2021). Obviously, this is also affected by the properties of the waste, as mortar containing CCA waste has a lower density than mortar including other wastes, such as bagasse ash. From these analyses (mass loss and mass density), it can be determined that the type of waste influences the properties of each of these hardened concretes.

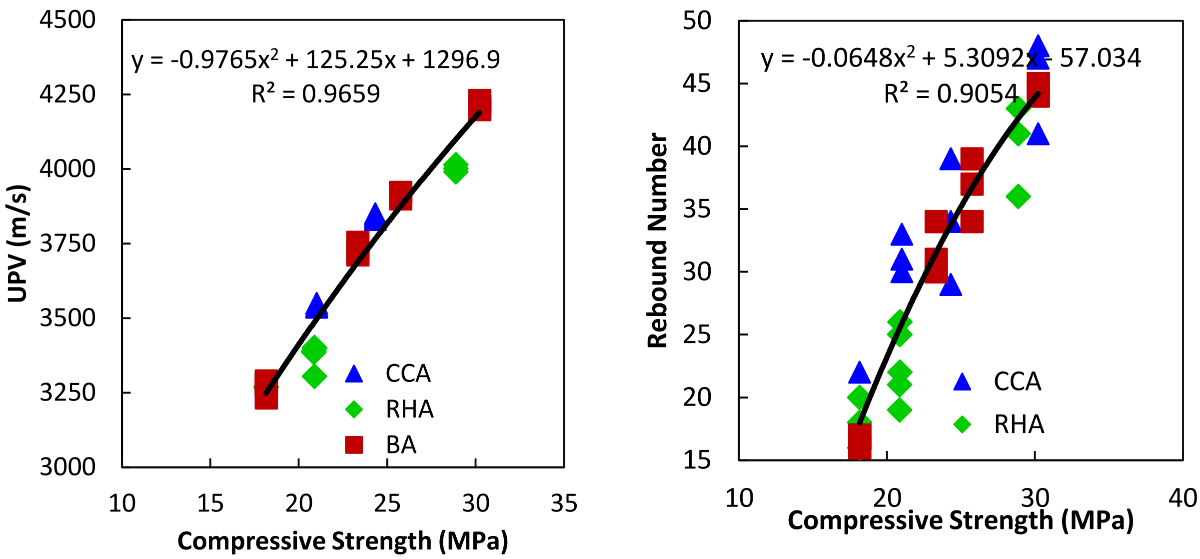
Non-destructive Tests (Ultrasonic Pulse Velocity Test and Hammer Test)

Generally, this non-destructive test is used to compare compressive strength results. Using the UPV and rebound hammer tests, non-destructive assessments were conducted. The results of non-destructive testing on specimens that are 28 days old are shown in Figure (14). The results of the UPV test show that the velocity rate has increased along with the increasing amount of agricultural waste utilized. The same trend can be observed in the rebound hammer test results, where the rebound number has increased with the increase of agricultural waste used as a fine aggregate replacement for mortar.



(a) UPV test (b) Rebound hammer test

Figure (14): Relationship between the amount of agricultural waste and the results of UPV test and rebound hammer test



(a) UPV test (b) Rebound hammer test

Figure (15): Comparison of compressive strength between (a) UPV test and (b) rebound hammer test

Figure (15) compares the UPV test results and the rebound hammer test results. The results of these two tests can be used to derive a polynomial equation with a correlation coefficient higher than 0.900. It should be noted that the obtained equation represents a combination of all agricultural waste types. This is because these three types of waste exhibit compressive strength trends and identical UPV and hammer tests among specimens with the same variant. The equation results can therefore be used for all three types of waste.

CONCLUSIONS

Based on the experimental results that have been discussed above, some conclusions can be drawn as follows.

1) Mortar containing agricultural wastes has inferior fresh properties compared to normal fresh mortar. This is due to the waste ability to absorb large amounts of water. The rise in waste quantity results in a decrease in workability.
2) The compressive strength of 3-day-old mortar decreased as the amount of agricultural waste increased. However, the compressive strength at 28 days showed that when the amount of agricultural waste increased, the compressive strength increased significantly.
3) The results of the hardened properties tests for water absorption, porosity, mass loss, and mass density for the three wastes follow the same trend. Bagasse ash waste is always more effective than rice husk ash and corn cob ash wastes.
4) The correlations between the results of non-destructive tests, such as UPV test and rebound hammer test, and the compressive strength tests for all types of waste variants are strong correlations.
5) Based on this investigation, agricultural waste ashes can be widely used as fine aggregate replacement for mortar production. The results of hardened mortar show the positive trends to improve physical and mechanical properties. In addition, the utilization of these agricultural waste ashes possibly reduces the cost of mortar production and reduces the utilization of natural fine aggregate.

Acknowledgements

The authors would like to express appreciation to the Department of Civil Engineering, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta, for providing the laboratory to conduct this research. This study was supported by the Institute for Research and Innovation (LRI), Universitas Muhammadiyah Yogyakarta, for the 2022 fiscal year with grant number 20/RIS-LR/II/2022.

Conflict of Interests

The authors declare that they have no known or potential competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Abdullah, N.O., Fakhruddin, Bachtiar, R.D.W., and Rusni, N.K. (2021). "A sustainable environmental study on clamshell powder, slag, bagasse ash, fly ash, and corn cob ash as alternative cementitious binder". IOP Conference Series: Earth and Environmental Science, 841 (012003), 1-8. https://doi.org/10.1088/1755-1315/841/1/012003

Adesanya, D.A., and Raheem, A.A. (2009). "Development of corn cob ash-blended cement". Construction and Building Materials, 23 (1), 347-352. https://doi.org/ 10.1016/j. conbuildmat.2007.11.013

Arici, E., Celik, E., and Kelestemur, O. (2021). "An analysis of the engineering properties of mortars containing corn cob ash and polypropylene fiber using the Taguchi and Taguchi-based grey relational analysis methods". Case Studies in Construction Materials, 15 (e00652), 1-15. https://doi.org/10.1016/j.cscm.2021. e00652

ASTM International. (2016a). "ASTM D6023-16: Standard test method for density (unit weight), yield, cement content, and air content (gravimetric) of controlled low-strength material (CLSM)". American Standards Testing Materials. West Conshohocken, United States. https://doi.org/ 10.1520/D6023-16

ASTM International. (2016b). "ASTM C597-16: Standard test method for pulse velocity through concrete". American Standards Testing Materials". West Conshohocken, United States. https://doi.org/10.1520/ C0597-16

ASTM International. (2018). "ASTM C805/C805M-18: Standard test method for rebound number of hardened concrete". American Standards Testing Materials. West Conshohocken, United States. https://doi.org/10.1520/ C0805_C0805M-18

ASTM International. (2021a). "ASTM C595/C595M-21: Standard specification for blended hydraulic cements". American Standards Testing Materials. West Conshohocken, United States. https://doi.org/10.1520/ C0595_C0595M-21

ASTM International. (2021b). "ASTM C230/C230M-21: Standard specification for flow table for use in test of hydraulic cement". American Standards Testing Materials. West Conshohocken, United States. https://doi.org/ 10.1520/C0230_C0230M-21

ASTM International. (2021c). "ASTM C109/C109M-21: Standard test method for compressive strength of hydraulic cement mortars (using 2-in or [50 mm] cube specimens)". American Standards Testing Materials. West Conshohocken, United States. https://doi.org/ 10.1520/ C0109_C0109M-21

ASTM International. (2022). "ASTM C1403-22a: Standard test method for rate of water abruption of masonry mortars". American Standards Testing Materials. West Conshohocken, United States. https://doi.org/10.1520/ C1403-22A

Aswin, M., Nola, L., and Maranatha, E. S. (2021). "Study on concrete compressive strength due to the cement substitution partially by corncob ash". IOP Conference Series: Materials Science and Engineering, 1123(012025), 1-9. https://doi.org/10.1088/1757-899X/1122/1/012025

Athira, G., Bahurudeen, A., and Appari, S. (2019). "Sustainable alternatives to carbon intensive paddy field burning in India: A framework for cleaner production in agriculture, energy, and construction industries". Journal of Cleaner Production, 236 (117598), 1-25. https://doi.org/ 10.1016/j.jclepro.2019. 07.073

Bendixen, M., Iversen, L.L., Best, J., Franks, D.M., Hackney, C.R., Latrubesse, E.M., and Tusting, L.S. (2021). "Sand, gravel, and UN sustainable development goals: Conflicts, synergies, and pathways forward". One Earth, 4 (8), 1095-1111. https://doi.org/10.1016/ j.oneear.2021.07.008

Bhattacharya, S.C., Salam, P.A., Runqing, H., Somashekar, H.I., Racelis, D.A., Rathnasiri, P.D., and Yingyuad, R. (2005). "An assessment of the potential for non-plantation biomass resources in selected Asian countries for 2010". Biomass and Bioenergy, 29 (3), 153-166. https://doi.org/ 10.1016/j.biombioe.2005.03. 004

Charitha, V., Athira, V.S., Jittin, V., Bahurudeen, A., and Nanthagopalan, P. (2021). "Use of different agro-waste ashes in concrete for effective upcycling of locally available resources". Construction and Building Materials, 285 (122851), 1-17. https://doi.org/10.1016/ j.conbuildmat. 2021.122851

Chusilp, N., Jaturapitakkul, C., and Kiattikomol, K. (2009). "Utilization of bagasse ash as a pozzolanic material in concrete". Construction and Building Materials, 23 (11), 3352-3358. https://doi.org/10.1016/j.conbuildmat.2009. 06.030

Cordeiro, G.C., Filho, R.D.T., and Fairbairn, E.M.R. (2009). "Effect of calcination temperature on the pozzolanic activity of sugar cane bagasse ash". Construction and Building Materials. 23, 3301-3303. https://doi.org/ 10.1016/j.conbuildmat.2009.02.013

Danish, A., Salim, M. U., and Ahmed, T. (2019). "Trends and developments in green cement: A sustainable approach". Sustainable Structures and Materials an International Journal, 2 (1), 45-60. https://doi.org/ 10.26392/SSM.2019. 02.01.045

Della, V.P., Kuhn, I., and Hotza, D. (2002). "Rice husk ash as an alternate source for active silica production". Materials Letters, 57 (4), 818-821. https://doi.org/ 10.1016/S0167-577X(02)00879-0

Djamaluddin, A.R., Caronge, M.A., Tjaronge, M.W., Rahim, I.R., and Noor, N.M. (2018). "Abrasion resistance and compressive strength of unprocessed rice husk ash concrete". Asian Journal of Civil Engineering, 19, 867-876. https://doi.org/10.1007/ s42107-018-0069-5

Gavriletea, M.D. (2017). "Environmental impacts of sand exploitation: analysis of sand market. Sustainability, 9 (7), 1-26. https://doi.org/10.3390/su9071118

Ghunimat, D., Alzoubi, A.E., Alzboon, A., and Hanandeh, S. (2023). "Prediction of concrete compressive strength with GGBFS and fly ash using multilayer perceptron algorithm, random forest regression and k-nearest neighbor regression". Asian Journal of Civil Engineering, 24, 169-177. https://doi.org/10.1007/ s42107-022-00495-z

Gooi, S., Mousa, A. A., and Kong, D. (2020). "A critical review and gap analysis on the use of coal bottom ash as a substitute constituent in concrete". Journal of Cleaner Production, 268 (121752), 1-26. https://doi.org/10.1016/ j.jclepro.2020.121752

Guo, H., Shi, C., Guan, X., Zhu, J., Ding, Y., Ling, T.C., Zhang, H., and Wang, Y. (2018). "Durability of recycled aggregate concrete: A review". Cement and Concrete Composites, 89, 251-259. https://doi.org/ 10.1016/j.cemconcomp.2018.03.008

Imbabi, M.S., Carrigan, C., and McKenna, S. (2012). "Trends and developments in green cement and concrete technology". International Journal of Sustainable Built Environment, 1, 194-216. http://dx.doi.org/10.1016/j.ijsbe. 2013.05.001

Jain, K.L., Sharma, D.K., Choudhary, R., and Bhargava, S. (2023). "Impact of waste iron slag on mechanical and durability properties of concrete". Jordan Journal of Civil Engineering, 17 (1), 45-57. https://doi.org/ 10.14525/JJCE. v17i1.05

Jimenez-Quero, V.G., Martinez, F.M.L., Garcia, P.M., Tiburcio, C.G., and Nava J.G.C. (2013). "Influence of sugarcane bagasse ash and fly ash on the rheological behavior of cement pastes and mortars". Construction and Building Materials, 40, 691-701. https://doi.org/ 10.1016/ j.conbuildmat.2012.11.023

Joshaghani, A., and Moeini, M.A. (2018). "Evaluating the effects of sugarcane bagasse ash and rice husk ash on the mechanical and durability properties of mortar". Journal of Materials in Civil Engineering, 30 (7), 1-14. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002317

Jung, S.W., Saraswathy, V., Karthick, S., Kathirvel, P., and Kwon, S.J. (2018). "Micro-structure characteristic of fly ash concrete with rice husk ash and limestone powder". International Journal of Concrete Structures and Materials, 12 (17), 1-9. https://doi.org/10.1186/ s40069-018-0257-4

Lima, C.P.F.D. & Cordeiro, G. C. (2021). "Evaluation of corn straw ash as supplementary cementitious material: Effect of acid leaching on its pozzolanic activity". Cement, 4 (100007), 1-13. https://doi.org/10.1016/ j.cement.2021. 100007

Mildawati, P., Puri, A., and Handayani, M.Z. (2022). "Effects of corn stalks ash as a substitution material of cement due to the concrete strength of rigid pavement". Journal of Geoscience Engineering Environment and Technology, 7 (1), 21-26. https://doi.org/10.25299/ jgeet.2022.7.1.4681

Monika, F., Prayuda, H., Cahyati, M.D., Augustin, E.N., Rahman, H.A., and Prasintasari, A.D. (2022). "Engineering properties of concrete made with coal bottom ash as sustainable construction materials". Civil Engineering Journal, 8 (1), 181-194. https://doi.org/ 10.28991/CEJ-2022-08-01-014

Muthadhi, A., and Kothandaraman, S. (2010). "Optimum production conditions for reactive rice husk ash". Materials and Structures, 43, 1303-1315. https://doi.org/10.1617/ s11527-010-9581-0

Pode, R. (2016). "Potential applications of rice husk ash waste from rice husk biomass power plant". Renewable and Sustainable Energy Reviews, 53, 1468-1485. http://dx.doi. org/10.1016/j.rser.2015.09.051

Pok, P., Julnipitawong, P., and Tangtermsirikul, S. (2021). "Properties of cement-fly ash mixtures with substandard fly ash as a partial cement and fine aggregate replacement". Asian Engineering Journal, 11 (3), 71-88. http://dx.doi.org/ 10.11113/aej.v11.16873

Prayuda, H., Monika, F., and Cahyati, M.D. (2020). "Fresh properties and compressive strength of self-compacting concrete with fines aggregate replacement using red brick powder and rice husk ash". World Journal of Engineering, 17 (4), 473-480. http://dx.doi.org/ 10.1108/WJE-08-2019-0236

Prayuda, H., Monika, F., Passa, S.A., Lubis, R.A., and Wibowo, D.E. (2023). "Engineering properties of mortar with untreated agricultural waste ashes as cement replacement materials". Innovative Infrastructure Solutions, 8 (227), 1-21. https://doi.org/ 10.1007/s41062-023-01200-y

Raharjo, A.S., Kurniawan, I., Gifary, M.W., Yosi, N.W., Sasmita, P.H., Fawzi, M., and Bayuaji, R. (2017). "The influence sugarcane bagasse ash and metakaolin on mechanical properties fly ash geopolymer paste". Asian Journal of Applied Science, 5 (4), 650-655. https://192.99.73.24/index.php/AJAS/article/view/4915

Rithuparna, R., Jittin, V., and Bahurudeen, A. (2021). "Influence of different processing methods on the recycling potential of agro-waste ashes for sustainable cement production: A review". Journal of Cleaner Production, 316 (128242), 1-29. https://doi.org/10. 1016/j.jclepro.2021. 128242

Saleh, F., Gunawan, M.A., Yolanda, T.I., Monika, F., Prayuda, H., Cahyati, M.D., and Pratama, M.M.A. (2022). "Properties of mortar made with bottom ash and silica fume as sustainable construction materials". World Journal of Engineering. http://dx.doi.org/ 10.1108/WJE-08-2021-0481

Saleh, F., Prayuda, H., Monika, F., and Pratama, M.M.A. (2019). "Characteristics comparison on mechanical properties of mortars using agriculture waste as a cement replacement material". IOP Conference Series: Materials Science and Engineering, 650(012039), 1-10. http://dx.doi.org/10.1088/1757-899X/650/1/012039

Sambangi, A., and Eluru, A. (2022). "Role of copper slag in the improvement of strength, quality, and durability of high-strength self-compacting concrete: An industrial waste". Asian Journal of Civil Engineering, 23, 961-971. https://doi.org/10.1007/s42107-022-00466-4

Sanal, I. (2018). "Significance of concrete production in terms of carbon dioxide emissions: social and environmental impacts". Politeknik Dergisi, 21 (2), 369-378. https://doi.org/10.2339/politeknik.389590

Sancheti, G., Jain, K.L., and Bhargava, S. (2020). "Mechanical and durability performance of concrete made with waste marble and fly ash". Jordan Journal of Civil Engineering, 14 (3), 305-318.

Schneider, M., Romer, M., Tschudin, M., and Bolio, H. (2011). "Sustainable cement production-present and future". Cement and Concrete Research, 41, 642-650. http://dx.doi.org/10.1016/j.cemconres.2011.03.019

Streets, D.G., Yarber, K.F., Woo, J.H., and Carmichael, D.R. (2003). "Biomass burning in Asia: annual and seasonal estimates and atmospheric emissions". Global Biogeochemical Cycles, 17 (4), 1-20. https://doi.org/ 10.1029/2003GB002040

Tam, V.W.Y., Soomro, M., and Evangelista, A.C.J. (2018). "A review of recycled aggregate in concrete applications (2000-2017)". Construction and Building Materials, 172, 272-292. https://doi.org/10.1016/j. conbuildmat.2018.03.240

Thomas, J.V., and Thomas, R.M. (2022). "Improvement in field applicability of concrete using fly ash and ground granulated blast furnace slag by sodium silicate activation". Asian Journal of Civil Engineering, 23, 336-349. https://doi.org/10.1007/s42107-022-00426-y

Wahyuni, A.S., Supriani, F., Elhusna, and Gunawan, A. (2014). "The performance of concrete with rice husk ash, seashell ash and bamboo fibre addition". Procedia-Engineering, 95, 473-478. https://doi.org/10.1016/j. proeng.2014.12.207

Wesseling, J.H., and Vooren, A.V.D. (2017). "Lock-in on mature innovation systems: the transformation toward clean concrete in the Netherlands". Journal of Cleaner Production, 155, 114-124. http://dx.doi.org/10.1016/j.jclepro.2016.08.115

Xiao, J., Li, W., Fan, Y., and Huang, X. (2012). "An overview of study on recycled aggregate concrete in China (1996-2011)". Construction and Building Materials, 31, 364-383. https://doi.org/10.1016/j.conbuildmat.2011.12.074