Combining pozzolanic material as ternary binder in Recycled Aggregate Concrete (RAC) to develop a new sustainable concrete

M A Tambichik¹, A A A Samad¹, N Mohamad¹, M Z M Bosro¹, M. A. Iman ¹

¹ Department of Structural and Material Engineering, Faculty of Civil and Environment Engineering, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia
Corresponding author: azizsamad14@gmail.com

Abstract: The demand for a sustainable concrete has increasing due to the effect of conventional concrete that led to many environmental problems such as carbon dioxide emission and depletion of natural resources. Hence, this paper discusses about the usage of ternary binder in recycled aggregate concrete (RAC). Ternary binder was developed from combination of palm oil fuel ash (POFA) Class C and rice husk ash (RHA) Class F as partial cement replacement. This study consists of two (2) phases that are; phase 1 to determine the optimum percentage of ternary binder and phase 2 to determine the compressive strength of recycled aggregate concrete with ternary binder system. Compressive test was conducted for 7 and 28 days to determine the compressive strength. The results show that existence of POFA and RHA as pozzolan for ternary binder help to improved strength of RAC. Combinations of 10% POFA + 15% RHA + 20% RA produce a compressive strength up to 32.8 MPa at 28 days. Increasing of RA content up to 20% will reduce the compressive strength. Overall it can be concluded that combination of POFA and RHA as ternary binder in RAC can produce a concrete with satisfactory strength for structural purposed.

1. Introduction
The use of sustainable concrete or green concrete in construction industry is needed due to the negative effect of conventional concrete and numerous benefits of using greener concrete. The demand of using this type of concrete has been spurred by demand for high quality concrete product, the national objectives to reduce greenhouse gas emission, the need for conservation of natural resources, and limited landfill spaces. This sustainable concrete comes in various types such as by utilizing pozzolanic material for replacing cement, geopolymer concrete, using recycled concrete aggregate, and addition of waste fiber in concrete.

In Asia, agricultural industry is one of the sources that contribute to the production of waste. Common agricultural wastes produce such as Palm Oil Fuel Ash (POFA) and Rice Husk Ash (RHA). There are about 3.1 million hectares of oil palm trees especially in Malaysia that produce over 9 million tons of crude oil. Oil palm plantation has contributed to the production of POFA. POFA is a by-product of oil mill arising from the uses of palm oil shell and palm oil bunches which are used to power oil mill plants for generate electricity [1].

Meanwhile, RHA is basically an agricultural residue obtained from rice processing mill. Only a small amount of husk produced was used as fuel in rice mill and electricity generating power plant.
Then, the by-product from burning the rice husk about 20% of its original weight is RHA [2]. Because of its huge amount of waste, the government needs to assign more hectares of landfill for disposal and spend a lot of money for transferring the waste to the landfill. The growing environmental concern, increasing scarcity of landfill, and depleting quality source of virgin aggregated are the problems that promote recycling of construction waste including concrete [3]. Recycled Aggregate Concrete (RAC) was made from using Recycled aggregate (RA) as replacement for virgin coarse aggregate in concrete. Recently, the use of more than one type of cement replacing materials in concrete, called ternary, quaternary, or multi binder concrete, has globally grown because they present some advantages over the binary binder concrete [4][14]. A ternary mixture was consist of portland cement and two other material as binder, blended either at the cement plant or at the batch plant. The materials for blended can be supplementary cementitious material (SCM) such as fly ash, metakaolin, pofa or rha.

Previous researcher has tried to utilizing binary and ternary binder in RAC to improve it mechanical properties. Faiz [5] study on the combination of silica fume with RAC and observed that 10% silica fume + 50% RA and 40% slag can improve compressive strength and indirect tensile strength. Radonjanin [6] develop a green recycled aggregate concrete (GRAC) with combination of RA with several pozzolan such as fly ash, metakaolin, milled lime stoned, and silica fume found that the strength of GRAC composite is lower than normal concrete. Hence, this study will be focusing on combining pozzolanic material as ternary binder in RAC to develop a new sustainable concrete.

2. Experimental Works

2.1. Procedure
This experimental program consists of two (2) phases that are:

Phase 1: To determine an optimum percentage for combination of POFA and RHA as ternary binder

   Phase 1(a) (Optimum percentage of POFA and RHA)
In this phase, the optimum percentage for POFA and RHA in a concrete was determined by conducting a compressive test for 7 and 28 days according to BS EN 12390-3:2009[10]. POFA and RHA were replaced at 10 %, 15 %, 20 %, 25 % and 30 % by weight of cement. At 28 days, percentages for POFA and RHA that achieved the target strength of 30MPa and higher was selected for phase 1(b).

   Phase 1(b) (Optimum percentage for combination POFA and RHA)
Next, the optimum percentage for combination of POFA with RHA was determined by conducting a compressive test for 7 and 28 days according to BS EN 12390-3:2009[10]. Percentage for combination was depending on compressive strength result at phase 1(a). The optimum combination percentage (POFA + RHA) was used for producing ternary binder.

Phase 2: To determine the optimum percentage for combination of ternary binder with RA

At this phase, an optimum percentage of Recycled Aggregate (RA) combined with ternary binder was determined by conducting compressive test for 7 and 28 days according to BS EN 12390-3:2009[10]. The percentage of RA used was 10%, 20%, 30%, 40% and 50% by weight of natural coarse aggregate.

3. Material Preparation

3.1. Cement
Ordinary Portland cement type 1 was used for this study. The cement conforms to BS EN 197-1:2011 Cement composition, specification and conformity criteria for common cement [11].
3.2. Superplasticizer
Superplasticizer (Estop Admix AP 20L) was added to improve concrete workability. In this study, the dosage was fixed at 0.6% from weight of binder.

3.3. Coarse Aggregate
Natural aggregate and recycled aggregate with maximum size of 9.5 mm was two types of coarse aggregate used for this experiment. The natural aggregate made from crushed stone is shown clearly in Figure 1(a). The specific gravity at saturated surface dry condition (SSD) of natural aggregate was 2.75. Meanwhile, for RA, as shown in figure 1(b), is obtained by crushing disposal concrete cubes ranging from C25 to C35 samples using a concrete crusher. Then it been sieved through a sieve with size 9.5 mm to 5mm. Lastly, Lost Angeles Abrasion (LA) machine was used for grinding the RA as to ensure the removal of excess mortar covering the RA.

![Figure 1. Types of coarse aggregate (a) Natural Coarse Aggregate (b) Recycle Aggregate](image)

3.4. Fine Aggregate
For fine aggregates, river sand which passed through 5 mm sieve and had a fineness modulus and specific gravity of 2.88 and 2.65 respectively. It was stored in a storage tank to prevent moisture.

3.5. Palm Oil Fuel Ash (POFA)
Palm Oil Fuel Ash (POFA) used in this study is obtained from Bell Oil Palm Plantation located at Parit Sulong, Batu Pahat, Johor, as shown in figure 2. Initially, the ash was put in the oven at temperature of 100 ± 5 degree Celsius for 24 hours. Then it was followed by sieving using 300 micron sieves to remove impurities and also reduce carbon that affect the pozzolanic properties. After that it was put in the Los Angeles Abrasion machine with 10 steel balls for 2 hours to make it finer than its original size and to ensure it passes the 150 micron sieve.
3.6. Rice Husk Ash (RHA)
Rice Husk Ash (RHA) used in this experiment is obtained from Kilang Beras Jelapang Selatan (M) Sdn Bhd, Muar, Johor rice as shown in figure 3. The ash has been put in the oven for 24 hours at a temperature of 100 ± 5 degree Celsius. Then it was sieved through 300 micron sieve to remove impurities and carbon. After that, it was grind using Lost Angeles Abrasion (LA) with 10 steel balls for 2 hours to make it finer than its original size and passing 150 micron sieve.

4. Concrete mix design
American Concrete Institute (ACI) was used to design the concrete with targeted strength of 30MPa at 28 days. The water cement ratio used was 0.57 according to Table 6.3.4(a) in ACI design.

| Quantity | Cement (kg/m³) | Water (kg/m³) | Sand (kg/m³) | Coarse Agg (kg/m³) |
|----------|----------------|---------------|--------------|-------------------|
| 1 m³     | 400            | 228           | 931          | 756               |

Figure 2. Palm Oil Fuel Ash (POFA)

Figure 3. Rice Husk Ash (RHA)
5. Result and discussion

5.1. Phase 1: Optimum percentage of ternary binder in recycled aggregate concrete (RAC)

5.1.1 Phase 1(a): Optimum percentage of POFA and RHA. In phase 1(a), compressive strength for concrete containing POFA (figure 4) and RHA (Figure 5) was determined. Percentage that achieved compressive strength of 30 MPa at 28 days was selected to be used at phase 1(b).

**Figure 4.** Compressive strength of POFA in concrete.

Based on figure 4, it shows that compressive strength of concrete with POFA decreases as the percentage of replacement increases. The highest compressive strength is recorded at 10% of replacement with 32.4 MPa but it still 13.2% lower than control specimen. Increase of POFA percentage more than 10% shows a continuous decrease in compressive strength. Reduction in compressive strength as the percentage of POFA increase is due to the excessive POFA addition which has created void inside the concrete due to problem of particle packing. However, it can be seen that 10%, 15%, and 20% replacement of POFA has achieved target strength of 30MPa at 28 days. Hence, the three percentages of replacement have been selected to be used for combination with RHA.

**Figure 5.** Compressive strength of RHA in concrete.

Figure 5 shows the compressive strength result of concrete containing RHA at 7 and 28 days. Based on the result, it also seems that increases of RHA replacement will decrease the compressive strength. 10% replacement of RHA produces a nearly similar strength with control specimen that is 36 MPa at 28 days. It can also be observed that the addition of RHA increases the compressive strength due to the filler effect. However, a low compressive strength is recorded at early age due to slower hydration.
process by RHA. Increase of RHA more than 10% has reduced the compressive strength and this result is similar to Kishore [12] where they also found that increase of RHA more than 10% leads to decrease in compressive strength. This result is also similar to the percentage of POFA, only 10%, 15%, and 20% of RHA replacement achieved the targeted strength of 30MPa at 28 days. Hence, this percentage is the best percentage and been selected for combination with POFA.

5.1.2 Phase 1(b): Optimum percentage for combination of POFA with RHA. In phase 1(b), the percentage for POFA and RHA that achieve target strength of 30 MPa is selected for determine the optimum combination of both materials. The compressive strength result at 7 and 28 days is shown in figure 6 below.

![Figure 6. Compressive strength for combination of POFA and RHA.](image)

From the result, can be seen that combination of 10% of POFA with 10% of RHA has the highest compressive strength compared to other percentage at 28 days. For P10R10, the compressive strength at 28 days is 34.7MPa and it is 5.7% slightly lower than the control specimen. Increasing percentage of RHA from 15% to 20% combined with 10% POFA has lowered the compressive strength. Reduction in compressive strength is due to the different physical and chemical properties of both materials that lead to the problem with particle packing and also lack of silica content that produces lower calcium silicate hydrate gel. Only P10 R10 and P10 R15 show a compressive strength of more than 30 MPa at 28 days. Hence, the optimum combination of POFA and RHA in concrete is at 10% POFA and 15% RHA because it has the highest replacement of waste and achieves target strength of 30MPa at 28 days. The optimum combination was selected to be used as fixed percentage for ternary binder in this study.

5.1.3 Phase 2: Optimum percentage for combination of ternary binder with RA. In phase 2, the optimum combination for POFA and RHA is combined with 10%, 20%, 30%, 40% and 50% of RA. The compressive strength result at 7 and 28 days is shown in figure 7.
Based on figure 7, it shows that the combination ternary binder with 20% RA has the highest compressive strength than other percentages. At 28 days, P10 + R15+ RA 20 have a compressive strength of 32.8 MPa but it is still lower than control specimen. The result of lower compressive strength than control specimen is similar with Kwan [13] where they also observe that replacing natural aggregate with RA will decrease the compressive strength respectively. From the graph, it can also be observed that with a suitable percentage of pozzolanic material combined in a recycled aggregate concrete, it can improve RAC properties. This can be attributed to the contribution by the pozzolanic reaction of silica in the POFA and RHA with the calcium hydroxide in the matrix, which produces additional calcium silicate hydrate (C-S-H) gels and reduces the pores and densifies the ITZ of RAC with the matrix. Only P10+R15+RA10 and P10+R15+ RA20 achieve 30 MPa at 28 days compared to other percentages. Therefore, based on both percentages, P10+ R15+RA20 is the optimum percentage for combination of ternary binder with RA in concrete due to the highest waste utilized and exceed the target strength.

6. Conclusion
The following conclusion can be drawn from the study above:

1. For the phase 1, the optimum combination for ternary binder (POFA + RHA) in a concrete was at 10% POFA+15% RHA. This combination produces a concrete with a compressive strength of more than 30 MPa and higher utilization of agricultural waste. The compressive strength recorded at 28 day was 31.4 MPa but it still lower than control specimen. Meanwhile for phase 2, the combination of RAC with ternary binder system could produce a concrete with a satisfactory strength. Combinations of ternary binder (10% POFA + 15% RHA) with 20% RA produce a compressive strength of 32.8 MPa at 28 days. The strength increases up to 4.4% when ternary binder was combined with RA. However, the strength was still lower than control.
2. The optimum percentage for combination of agricultural and construction waste in concrete can be used for the construction that needed a structural strength of 30 MPa as it can reduce the harmful effects of conventional concrete to the environment. Thus, this would ultimately lead to a sustainable construction and greener environment.

7. References

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