EFFECTS OF VARYING RECYCLED FINE AGGREGATE CONTENT AND WATER/CEMENT RATIO IN BEDDING MORTAR

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ABSTRACT

This paper presents the results from a research carried out with the aim of analysing the usability of Recycled Fine Aggregates (RFA) produced from Construction and Demolition Waste (CDW), in bedding mortar. Properties of RFA were compared to that of the Natural Fine Aggregates (NFA) in terms of Bulk Density, Fine Fraction, Particle Size Distribution, Water Absorption and Chloride Content and were tested for five mixed proportion scenarios of RFA and NFA at 0%, 25%, 50%, 75% and 100% RFA contents. RFA indicated a water absorption of 6.33% when compared to that of 0.71% for NFA (ordinary river sand). Mortar testing was further divided under three water/cement ratios at 0.5, 0.6 and 0.7. Bulk density gradually decreased with increased RFA content yet recorded an exceptional highest of 1476Kg/m^3 at 75%RFA. Results from fine fraction and particle size distribution indicated compatibility of RFA to replace NFA up to 50% RFA. Chloride content analysis indicated allowable RFA replacement levels up to 99% and 44% for bedding mortar and plastering mortar applications, respectively. Though higher water absorption demanded for higher water content, Compressive Strength increased with the increasing RFA content, even above NFA values, reaching a maximum of 15.2 ± 0.50 N/mm^2 at 75% RFA for 0.7 water/cement ratio while workability was within the acceptable range at 50% RFA at the same water content. The analysis in terms of fine aggregate properties and mortar properties showed that up to 50%, NFA can be substituted with RFA at water/cement ratio of 0.7 in bedding mortar which will also attribute to a cost reduction of minimum 50%, as well as to greatly reduce the disastrous environmental impacts from sand mining and waste disposal thus enhancing sustainability.

Keywords: *Compressive Strength; Construction and Demolition Waste (CDW); Workability.*

1. INTRODUCTION

With the significant technological development currently experienced worldwide, the rate of pollution and waste emission has increased significantly. Though municipal and industrial waste plays the major roles as waste streams, demolished construction waste has also being added to that list as another major stream of waste which is becoming important day by day due to the increase of construction activities. With the concept of recycling in rise, the focus has shifted to the use of recycled construction and demolished waste as an alternative for fine and coarse aggregates in the construction industry. In addition, rising demand for construction materials, increases depletion of raw materials such as sand and aggregates plus the environmental damage from material production has led to the popularity of this concept (COWAM, 2009).

Even though there are certain alternative fine aggregates like sea sand, quarry dust and dredged sand from silted reservoirs which have already been used in Sri Lanka, there are certain issues associated with each of these alternatives which have led to adverse effects. Corrosion issues associated with the excess salt and chloride content in sea sand and coastal erosion as a result of the sea sand dredging activities have made the use of this alternative problematic. Sand dredged from silted reservoirs and use of quarry dust have also failed to come into industrial use due to issues related to environmental effects as well as scarcity of these resources. This research focuses on the use of recycled aggregates which mainly formed from the waste generated from demolition of constructed structures, as an alternative for fine aggregates in bedding mortar. Demolition of a certain structure may occur due to reasons like, exceeding of the useful lifetime, demand for more sophisticated and space saving building designs or even due to natural disasters like tsunami or earthquakes (Shelter-Center, 2011).

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The major focus of this research is to study the suitability of the recycled fine aggregates to be used in bedding mortar and raise awareness for wider systematic use of recycled Construction and Demolition Waste in Sri Lanka as a construction material. Aspects to be considered when using recycled fine aggregates for construction purposes and to identify the limitations in recycled aggregate mortar preparation with respect to water/cement ratio, finer percentage and other important properties are studied under this research.

2. LITERATURE REVIEW

When analysing recent history, the use of recycled aggregates seems to be a very common practice all around the world, though it seems an unfamiliar territory in the Sri Lankan context. Instances for the use of Recycled Aggregates from CDW can be found mostly in developed countries like UK, Japan and Germany, where they have been used to construct building materials and paving bricks in the forms of mortar and concrete (Vyncke, 2001).

Particle size distribution, fine fraction, specific gravity, water absorption, bulk density and chloride content are some of the important aggregate properties that had been analysed to determine the suitability of fine aggregates for construction purposes. In terms of important mortar properties, workability and compressive strength characteristics of mortar have been analysed in previous researches (Thurston, 2011).

3. MATERIALS AND METHODS

3.1. PREPARATION OF SAMPLES

A bulk sample of RFA produced from demolished building waste was collected from the Construction Waste Management (COWAM) centre site in Galle and was used as the materials for testing.

3.2. TESTING OF FINE AGGREGATES

Followings tests were carried out to test the fine aggregate properties of recycled fine aggregates and natural fine aggregates while tests were done for five mixed proportion scenarios (RFA and NFA) at 0%, 25%, 50%, 75% and 100% RFA contents.

- Sieve Analysis Test - (ASTM C 144-84)
- Specific Gravity and Water Absorption Test - (BS 812-Part 2:1995)
- Bulk Density Test - (ASTM C 29-09)
- Fine Fraction - (ASTM C117-95)
- Chloride Content - (BS 1377-Part 3:1990)

3.3. TESTING OF MORTAR

To evaluate the properties of mortar made using RFA, the RFA were mixed with NFA under five different scenarios similar to the aggregate testing and were further tested under three water/cement ratios as indicated in Table 1.

Table 1: Mix Proportions Used for Mortar Testing

Scenario No.	% of Recycled Aggregates	% of Natural Aggregates	Water/cement Ratio
1	0	100	0.5 0.6 0.7
2	25	75	0.5 0.6 0.7
3	50	50	0.5 0.6 0.7
4	75	25	0.5 0.6 0.7
5	100	0	0.5 0.6 0.7

Following tests were done to determine the mortar properties.

- Workability of fresh mortar - (BS EN 1015-3)
- Compressive strength of test cubes - (BS 1377-part 2 : 1990)

The workability of each and every mix was tested prior to the making of mortar specimens. With regard to compressive strength testing, curing was carried out as per the BS standards after the preparation of the mortar specimens. The testing of those specimens was done for 7 days, 14 days and 28 days.

4. RESULTS AND DISCUSSION

Mortar is a mixture of fine aggregates, water and cement. Initially the properties of the RFA were compared to those of NFA in five mix proportions to analyse the effects of varying RFA content on aggregate properties.

4.1. *AGGREGATE TESTS*

When the particle size distribution results given in Figure 1, are considered the gradation curves for all five mixtures are mostly within the standard envelope accepted for fine aggregates to be used in bedding mortar applications.

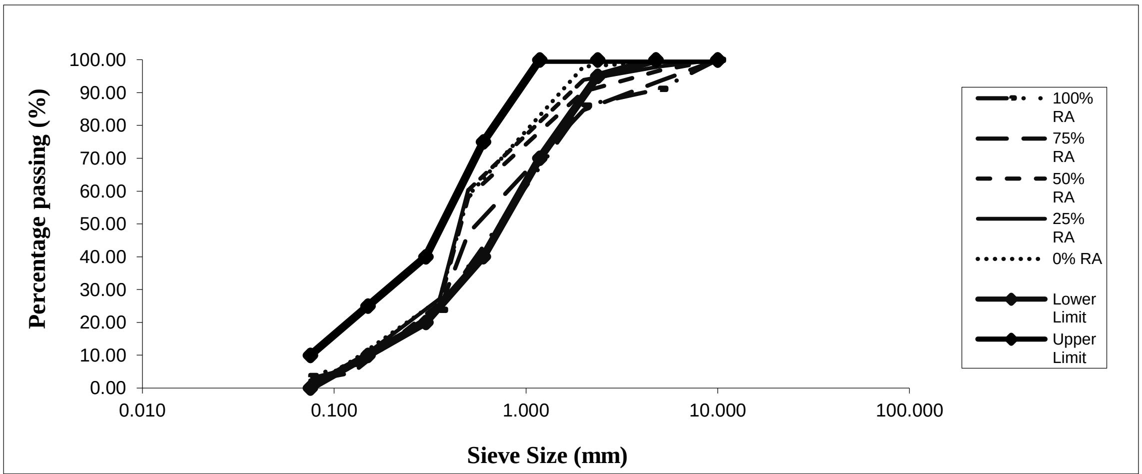

Figure 1: Percentage Passing (%) vs. Sieve Size (mm)

Further analysis with regard to fine fraction test indicates an inversely proportional relationship between the fine fraction and the decreasing RFA content. It reveals that RFA has higher amount of fine particles reaching a maximum of 13.47% at 100% RFA and being lowest at 1.51% for 0% RFA (i.e.100% NFA). The statistical analysis gives P values well within the acceptable range of difference, making the results highly reliable.

Though according to standards, the fine content of 13.47% in RFA is within the acceptable limit of 30% for fine aggregates produced from crushed rock, it is expected to adversely affect properties of bedding mortar.

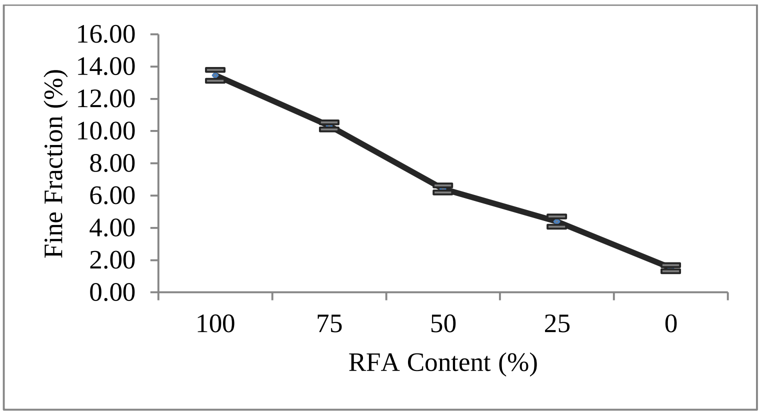

Figure 2: Fine Fraction (%) vs. RFA Content (%)

When considering the different parameters of fine aggregates bulk density is also another important parameter which differentiates the RFA from NFA. When considering the bulk density values for each mix proportion given in Figure 3, the P value (T-test) is less than 0.0001. By conventional criteria, this difference is considered to be extremely statistically significant.

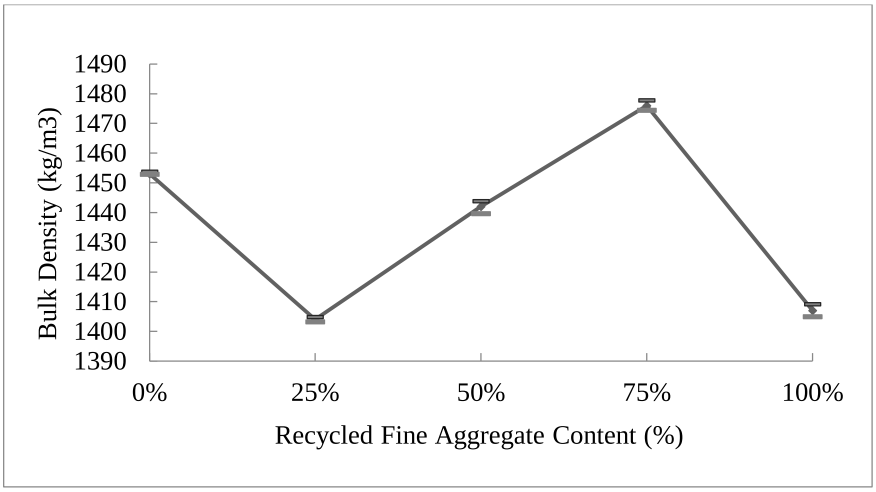

Figure 3: Bulk Density (kg/m^3) vs. RFA Content (%)

Generally the tendency indicated is for the bulk density to decrease with the RFA content due to the increase in microspores resulting in values of 1453kg/m^3 and 1407kg/m^3 at 0% and 100% RFA respectively. Packing ratio of the particles which is one other factor which governs bulk density can be used to explain the maximum bulk density value of 1476kg/m^3 being recorded at 75% RFA content.

Water absorption is a vital characteristic of fine aggregates important in determining the water/cement ratio of the mortar mix. In this case, RFA shows relatively a higher water absorption of 6.33% compared to the normal values of 0.71% for NFA. This high water absorption can be traced back to the high fine content in RFA. The P value (T test) of Water Absorption of NFA and 100% RFA equals 1.03876×10^{-6} By conventional criteria, this value is considered to be within acceptable range, so the data are highly independent.

Table 2: Water Absorption (%) of RFA and NFA

Sample Type	NFA	RFA
Water Absorption (%)	0.71	6.33

Chloride content is basically an important aspect to consider especially when aggregates are utilised for constructions with embedded metallic components. Annexure D of BS EN 13139 recommends that the water soluble chloride content of the fine aggregates should not exceed 0.15% for bedding mortar and the limitation further narrows down to below 0.06% for mortar with embedded metallic appliances.

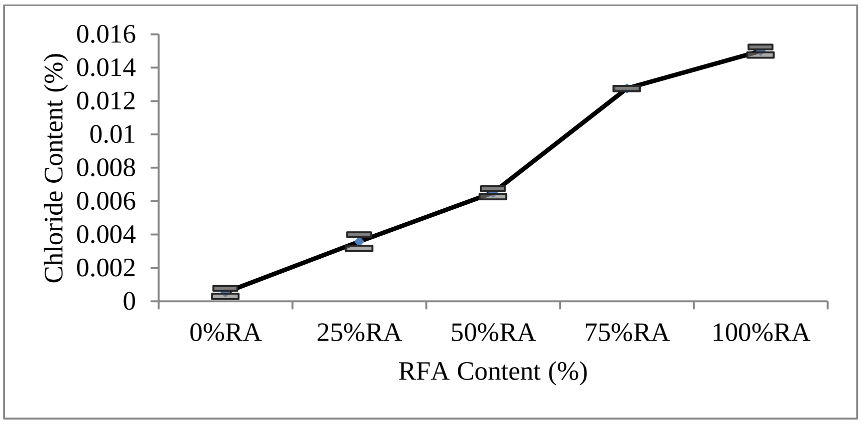

Figure 4: Chloride Content (%) vs. RFA Content (%)

When we consider the standard deviation and the P values for this data set it gives a value as low as 3.48 x 10-14, which is by conventional criteria can be considered to be not statistically significant difference, so the results are highly accurate.

When considering the basic applications for bedding purposes mixtures of up to 99% RFA content can be used within permissible chloride content. But when considering applications where mortar is used with embedded metals, aggregate mixtures up to 44% RFA can be used.

4.2. MORTAR TESTS

Proceeding to mortar testing, the mortar mixtures were made in accordance with the five mix proportions and further tested for three water/cement ratios of 0.5, 0.6 and 0.7 to analyse the effect of varying water content on properties bedding mortar made with RFA.

Initially the testing was carried out to determine workability which defines the convenience provided to mason when using the mortar for masonry applications. Mortars with high flow values or low flow values would cause inconvenience and would result in time consumption as well as structural failure. BS EN 1015-3 standard provides that flow values obtained for fresh mortars should be within 100-115% range for optimum workability.

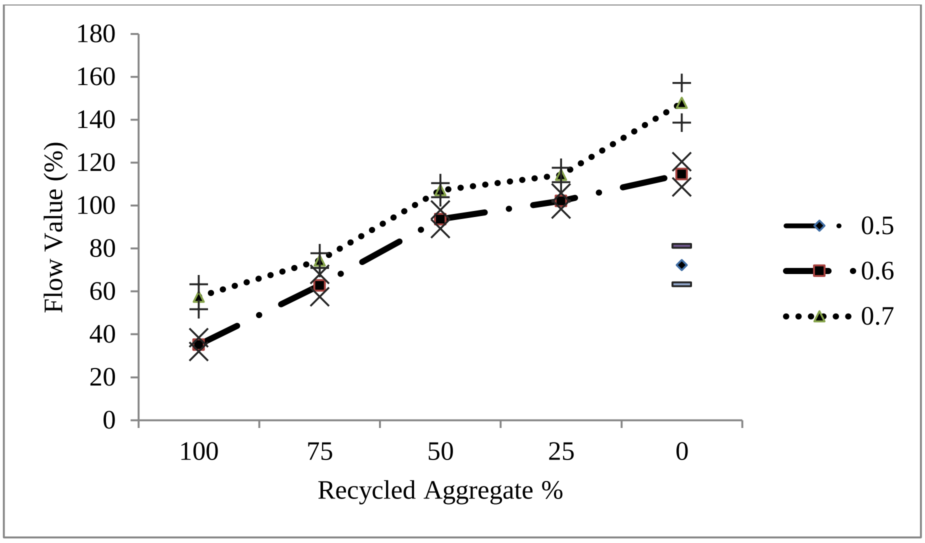

Figure 5: Flow Value (%) vs. RFA Content (%)

The statistical analysis of the 0.6 and 0.7 water cement ratios in the flow table test results in Figure 5 gives P values of 7 x 10^{-9} and 2 x 10^{-8} respectively which are well within the acceptable range of difference, making the results highly reliable. Water/cement ratio 0.5, indicated to be insufficient to provide acceptable flow values for any of the five mix proportions.

When 0.6 water/cement ratio is used, 100%, 75% and 50% RFA mixtures had low flow values. But the 25% and 0% RFA mixtures had acceptable flow values within 100% - 115% range. When the water/cement ratio was increased to 0.7 acceptable flow values were obtained for the 50% RFA and 25%. It is such that the increasing water content seems to increase the flow of mortar and when it passes the optimum level at 55 RFA% the RFA amount won't be enough to absorb the water content and the excess water would make it undesirable due to high flowing characteristics.

Compressive strength results in terms of 28 days strength given in Figure 6 can be considered as the most important characteristic in terms of strength and durability of hardened mortar. With time it is evident that all the compressive strength values had exceeded their respective 14 day and 7 day values indicated in Figures 7 and 8, respectively. When statically analysing of the graphs in Figure 6, the respective P values for 0.5, 0.6 and 0.7 water/cement ratio graphs are at 0.00026, 0.005 and 0.00029 meaning that they are within the conventionally allowable insignificant difference limits, making the results of these graphs more reliable.

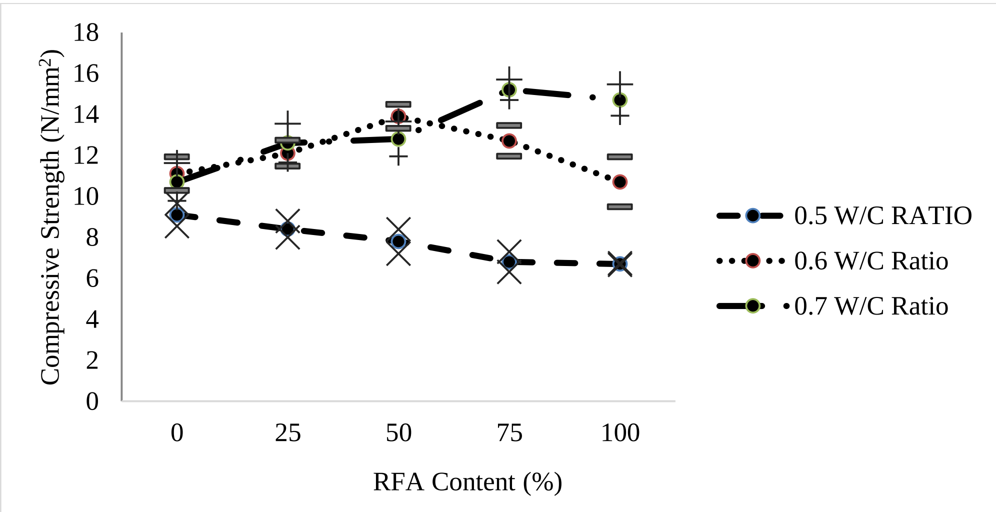

Figure 6: 28 Days Compressive Strength

With reference to the 0.5 water/cement ratio the compressive strength of the mortar cubes shows a declining trend, continuously from 0% to 100% RFA mixture. Lack of water required for bonding may have resulted in this phenomenon. With the high water absorbing characteristics of RFA, it is clear that when the RFA% is increased at 0.5 ratio the lack of water for bonding issue increases, resulting in a relatively steady decline in the compressive strength of mortar.

When the 0.6 water/cement ratio is considered, the trend seems to be an increase in compressive strength up to about 50% RFA content and then a declination. The initial increase in strength can be explained as due to the excess amount of water at 0.6 water/cement ratio which continues to be absorbed up to an optimum level when the RFA% is increased. But from the 50% RFA onwards, once again there seems to be a lack of water in mortar for bonding which decreases its compressive strength similar to the 0.5 ratio scenario.

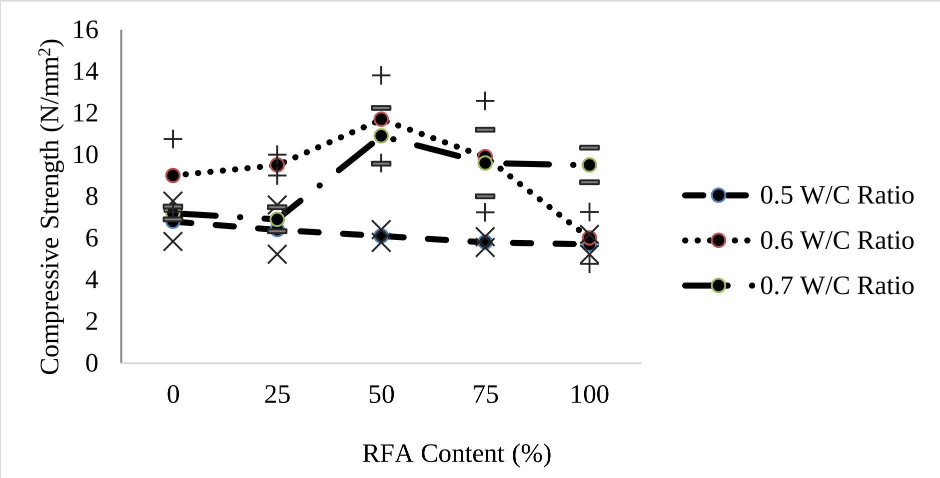

Figure 7: 14 Days Compressive Strength

Analysis of the 0.7 water/cement ratio data indicates a similar pattern by increasing in strength up to 75% RFA mixture and then on showing a dip. This may once again be due to the excess water the mortars up to 75% RFA contained and then on the lack of water due to the high water absorbance by the RFA.

The data variance and P values are relatively higher for the 14 day and 7 day results making the results less reliable. After analysing the 28 day results it is visible that the 14 day results also gives traces for a similar outcome as shown in in Figure 7.

When considering the 7 day compressive strength results in Figure 8, the values are randomly distributed making it evident that more time is required for the mortar bonds to settle into a steady state.

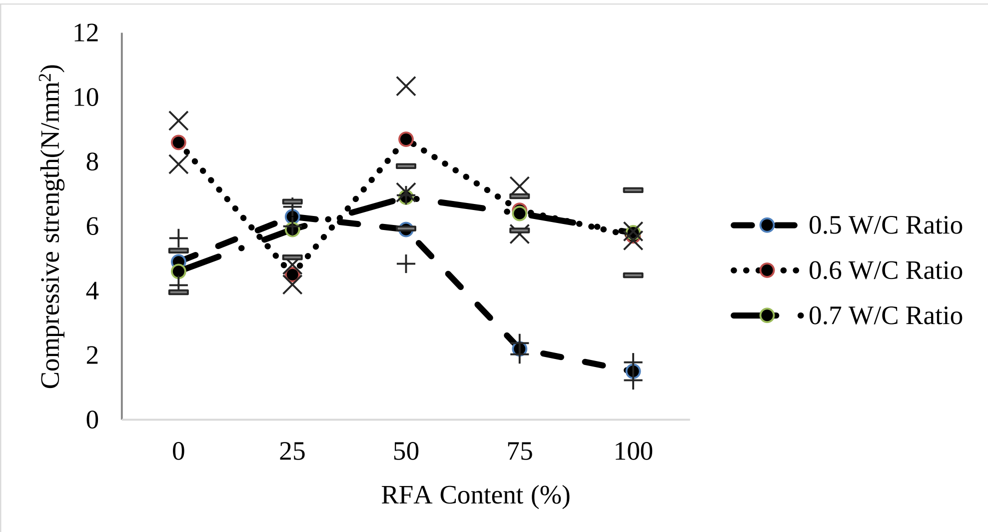

Figure 8: 7 Days Compressive Strength

5. CONCLUSIONS

Aggregate properties of RFA such as Bulk Density, Water Absorption, Fine Content and Chloride Content showed a relatively inferior yet acceptable quality when compared to that of NFA, mainly as a result of the higher fine content. Use of a washing process can be recommended to improve the quality of RFA. However, at water/cement ratios as high as 0.7 to compensate for the high water absorption, mortar made out of RFA showed lesser impacts on the compressive strength and workability when compared to that made from 100% NFA. The compressive strength values reached a maximum of 15.2 ± 0.50 N/mm^2 at 75% RFA for 0.7 water/cement ratio while workability was within the acceptable range at 50% RFA at the same water content. Under higher water/cement ratios of about 0.7, the compressive strength values shows a tendency to increase with the increase in RFA content, even above compressive strength values of NFA mortars.

Mortar made by using mixture of 50% RFA with 50% NFA, at water/cement ratio of 0.7, indicates to be most suitable for construction purposes since it has achieved the optimum workability as well as acceptable and higher strength values than 100% NFA leading to a 50% cost reduction as well as environmental sustainability.

6. ACKNOWLEDGEMENT

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