



The Sustainability of Cement Mortar with Raw Sewage Sludge and Rice Husk Ash

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Abstract

This study devotes to investigate the use of Raw Sewage Sludge (RSS) and Rice Husk Ash (RHA) to obtain sustainable construction materials. This study focuses on the evaluation of using cement-based materials having RSS and RHA. The methodology of this study could be summarized by replacing water by RSS and replacement of 10 %RHA from the weight of cement. Five groups have been used with different ratios of RSS/binder; for each group with and without RHA. In addition, the sand/binder ratio has been changed for Group 2. This method includes testing the flowability, compressive strength, Total Water Absorption (TWA) and density for the mortar mixes containing these materials. The results indicate that mixes with added materials encourage the results compared to control mixes. Addition of RHA considerably decreases flowability; however it enhanced compressive strength for all groups especially for Groups 3, 4 and 5. Moreover, the minimum values of TWA were recorded when 10% RHA was utilized as a cement replacement for both RSS and water mixes. Finally, it was found that replacing RSS by water, leads to the reduction in flowability and TWA in all mixes especially at 10% RHA; whereas the strength and density increase.

Keywords: Raw Sewage Sludge; Rice Husk Ash; Sustainability; Cement Mortar; Concrete.

1. Introduction

To reduce the cost of concrete construction, different studies are trying to figure out alternatives for the ingredients of concrete without a significant reduction in its strength [1]. These could be sustainable materials such as RHA and RSS.

The RHA is from the burning of rice husk which is very widespread in East and South-East Asia because rice production is so high in this area. The RHA is then utilized as a substitute or admixture in cement. Therefore the entire rice product is used in an efficient and environmentally friendly approach [2].

The RSS is a residual stream of suspended/dissolved organic and inorganic materials that result from the treatment processes of municipal wastewaters. The RSS is a liquid or semisolid liquid state depending on the percentage of solid by weight resulting from different processes applied [3]. The RSS may be collected from secondary and tertiary settlement tanks. The RSS is approximately produced up to 35 million tons per year in the UK [4].

The RSS as a water replacement was used with unprocessed fly ash as a cement replacement. The results of using RSS and unprocessed fly ash were encouraging. Better properties of engineering, durability and environmental comparing with the control mixes [5, 6].

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Alawn [7] used the RHA with cement mortar to investigate the optimum value for compressive and flexural strengths. The author used 5, 10, 15 and 20% of RHA as partial replacement by weight of cement. He found the 10% RHA gives the optimum strengths at 28 days and 15% at 90 days.

Siddika et al. [1] concluded that using RHA as partial replacement of cement reduces environmental pollutants and economy in concrete construction. In addition, they found that 10% RHA replacement gives the best values of compressive, flexural and tensile strengths. Whereas, the value of slump decreases with increasing in RHA replacement. Similarly, Zhang et al. [8] found that 10% RHA replacement gives the maximum strength than control mix at all ages. Ramezaniapour et al. [9] indicated that 10% RHA replacement of cement enhanced compressive of concrete from 40.3 MPa for control mix to 44.8 MPa and tensile strength from 3.87 MPa for control to 4.19 MPa for same curing age at 28 days.

Compressive strength of normal mortar cubes (1:4 mix) increases to 16.43 MPa and 17.44 MPa for RHA composition 7.5% and 10.0% respectively compared to control strength of 10.39 MPa but for higher proportion of 12.50%, 15.0% and 17.5% compressive strength decreases to 12.74 MPa, 7.71 MPa respectively for 28 days curing age [10].

Jaya et al. [11] conducted an experimental work on cement paste using nano silica produced from Black Rice Husk Ash (BRHA). The four ratios (0, 10, 20 and 30%) of BRHA by weight of cement were implemented. The authors were found that the cement paste comprising 10% nano BRHA displays a better pozzolanic reaction because of the highest weight loss of calcium silicate hydrate.

Having reported that 10% RHA gives better compressive and flexural strengths, this study has used 10% RHA replacement as the only ratio for this study. Whereas, for water either it was replaced totally with RSS or not with different RSS/cement ratios or water/cement ratio equals to 0.75 as in Hamood et al. (2017) and Hamood (2014) studies [5, 6]. The use of these have been used in this study.

2. RHA

Added cementitious materials may consider the most effective requirements of durable concrete. The RHA is considered as superior to other supplementary materials such as slag, silica fume and fly ash because they have high pozzolanic activity in addition, both strength and durability of concrete are enhanced [12]. The utilization of RHA as cement replacement is a new tendency in concrete technology. Moreover, to the extent that the sustainability is concerned, it may help in solving problems otherwise encountered in another way in waste disposal [13]. Disposal of husks is a major problem and open pile burning is unacceptable for environmental reasons, so most husks are currently entering the landfill. The disposal of rice husks creates an environmental problem that leads to the idea of replacing RHA with silica in the cement industry. The silica content in the ash is about 92-97%. Chemical compositions of RHA are affected by the combustion process and temperature. The silica content in the ash increases as the burning temperature increases. According to a study by Houston [14] RHA produced by burning RH between 600 and 700 °C for two hours, containing 90-95% SiO₂, 1-3% K₂O and <5% unburned carbon. Under controlled burning conditions in industrial furnaces, conducted by Mehta [15], RHA contains silica in a highly amorphous and cellular form, with an area of 50-1000 m² / g. Therefore, the use of RHA with cement modifies the operability and stability, and reduces the development of heat, thermal cracking and plastic shrinkage. This further develops strength, impermeability and durability by enhancing the transition zone, improving the pore structure, and preventing large voids in the hydro-cement paste through the pozzolanic reaction.

3. Sewage Sludge

The RSS is primarily obtained from the tanks of primary settlement. These tanks are large rectangular where heavier particles are permitted to settle down and are subsequently dredged by scrapers to a submerged outlet. Stable current, a thick slurry, is pumped to a sludge storage.

4. Materials Properties

The materials that have been utilized in the experimental program, containing Portland cement, fine aggregate, drinking water, RSS and RHA. Hydrated lime was also used as an additional material for other applications.

4.1. Portland Cement

Ordinary Portland cement (Type I) manufactured by AL-Kufa factory was used throughout in this project conforming to Iraqi specification [16].

4.2. Fine Aggregate

The graded standard sand used in this study was brought from engineering consulting bureau in Kufa University. Table 1 indicates the grading of this sand. The table also includes the limits specified by ASTM C 778 [17].

Table 1. Grading of the standard sand

Sieve	Percent retained	ASTM C778-1987 Limits
No.16 (1.18 mm)	None	None
No.30 (600 mm)	2	2 ± 2
No.40 (425 mm)	27	30 ± 5
No.50 (300 mm)	75	75 ± 5
No.100 (150 mm)	97	98 ± 2

4.3. Mixing Water

The water used in this work is a tap water from the laboratory.

4.4. RSS

The RSS was collected as a thick slurry which is formed 2.5% of total liquid weight was taken from a sewage treatment unit in Al-Brakih. The collected RSS in the form of thick slurry that has 97.5% total weight liquid and 0.5% total weight hydrated lime which has been added to the RSS for partial treatment in order to raise the level of alkalinity ($\text{PH} > 12$) for eliminating harmful pathogens.

4.5. RHA

The rice husks are plant fibers contain cellulose, hemicellulose, lignin and silica. The RHA is found to be superior to other supplementary materials such as slag, silica fume and fly ash. This is because of its high pozzolanic activity, both strength and durability of concrete enriched. The RH used in this experimental work was collected from Al-Najaf Silo for cereal (Figure 1), and then incinerated in an oven at heating rate of 10°C per minute up to 300°C kept at this temperature for 3 hours under well-controlled temperature, after that permitted to cool down to room temperature (Figure 1). The ash was then grinded.



Figure 1. Raw rice husk before and after burning

4.6. Hydrated lime

Hydrated lime has been used in order to partially treat the RSS. The percentage of this material is 0.5% of total weight of the RSS specimen to remove risky pathogens by rising PH more than 12.

4.7. Mixing Proportions

Mortar mixes with RSS and RHA were investigated throughout this experimental program. Nine of mortar mixtures mainly included a constant ratio of sand/binder of 3.0 with various liquid/binder ratios (0.5, 0.6, and 0.75). RHA was used as a cement replacement at ratio of 10% by the total mass of binder. The used ratio were determined depending on the previous studies, some practical guidance and several trial mixes. The ratio of 3 for sand/cement was considered [18]. However, other sand/cement ratios, containing 4.5 and 6.0, were inspected, too. The ratios of RHA have been decided depending on the results of the previous studies. The liquid content was determined from 0.5 to 0.75 to make workable mixes (the lower limit), and to prevent the separation of mixtures during casting (upper limit). The mixing proportions for these mortar mixes are presented in Table 2. These mixes were classified into five groups and as indicated in Table 3. These groups are:

- Group I: It is used to test the effect of changing RSS ratio on the inspected properties. One ratio of sand/cement is 3.0 and three ratios of (RSS/cement) are 0.5, 0.6, and 0.75 have been utilized.
- Group II: It is used to investigate the effect of sand ratio variation on the examined characteristics. One ratio (0.75) of RSS/cement was used and three ratios of sand/cement were 3.0, 4.5 and 6.0.

- Group III: This group is considered to assess the effect of partially changing cement with the RHA on the examined characteristics. Cement was changed with the RHA at 10% by binder total weight. The (RSS/binder) content is 0.6 in this group.
- Group IV: Like Group III, but with a high RSS/binder content (0.75).
- Group V: This group content is like Group IV, but with water.

Table 2. Mixing ratios with RSS and RHA

Mix	Liquid/Binder	Binder		Sand/binder ratio	Type of liquid
		Cement	RHA		
MX1	0.5	1.0	0.0	3.0	RSS
MX2	0.6	1.0	0.0	3.0	
MX3	0.75	1.0	0.0	3.0	
MX4	0.75	1.0	0.0	4.5	
MX5	0.75	1.0	0.0	6.0	
MX6	0.6	0.9	0.1	3.0	Water
MX7	0.75	0.9	0.1	3.0	
MX8	0.75	1.0	0.0	3.0	
MX9	0.75	0.9	0.1	3.0	

Table 3. Investigated properties for different mortar mixes

Group	Mix	Studied properties
I	MX1, MX2, and MX3	Flowability, compressive strength, density, and TWA.
II	MX4, and MX5	
III	MX6	
IV	MX7	
V	MX8, and MX9	

5. Mixing, Casting and Curing

Specimens were prepared of mortar mixes with ordinary Portland cement with or without RHA. These are mixed manually until homogeneity was attained. Then, RSS or water has been added and mixed as indicated in Table 2.

Regarding to the casting process, steel molds (70 mm in size) have been used to cast the mortar samples and compacted them using a vibration. The excess mortar was cut and removed with a trowel from the top of the specimen. These molds have been used for determining the compressive strength, density, and TWA.

After casting, samples have been protected with plastic sheets and located in a place at a temperature of 20 ± 2 °C for 24 hours until demolding. Therefore, specimen have been cured for various ages (between 7 and 28 days) by putting in water tanks until testing time. The water in the tank was changed every two or three weeks.

6. Testing

Different tests have been implemented in this study such as:

- Flowability (flow table test): the flowability test of fresh cement mortar mixes has been determined according to ASTM C230-08 specifications.
- Compressive strength test: the average strength of three cubes has been determined to the nearest 0.1 MPa. These specimens have been tested according to BS EN 196-1:2005.
- Density: this test was carried out in order to get information about the variation of void content due to the use of RSS in this study. It was implemented in $70 \times 70 \times 70$ mm in size samples. Mass of cured specimens (for 28 days) was determined by a sensitive scale with accuracy of 0.01 gm. The volume has been determined measuring the sample dimension by a precise caliber. Then, the density was measured by dividing the mass by the volume.
- TWA: this test was carried out on the same specimens which are used in the density test. Cured samples have been dried in an electrical oven at (105 ± 5) until a constant weight. High drying temperature has been evaded in order not to make any harms to the tested samples. Subsequently, dried samples have been positioned at a room temperature to cool down for 2 hrs., and mass has been later measured and documented to the nearest 0.1 gm.

Dried specimens have been submerged in a tap water for 48 hours and noting the increase in mass, then weighing it again. Prior to determining mass of saturated specimens, external surfaces have been dried by damp towels. TWA has been determined as in Equation 1.

$$TWA = (ms - md)/(md) \quad (1)$$

Where; *TWA*: TWA %; *ms*: Mass of staturated specimens (gm); *md*: Mass of dried specimens, (gm).

7. Results and Discussions

7.1. Flowability Test Results

The results of the flowability for each group has been summarized as below:

Effect of RSS (Group I)

The flowability with various RSS ratios is indicated in Figure 2. Group1 has three mixes (MX1, MX2, and MX3) and three ratios (0.5, 0.6 and 0.75) of RSS/cement have been inspected. For evaluation purposes, MX8 (which has a drinking water equal to the RSS of MX3), has been assessed, too. The figure indicates that the flowability of samples improved as the ratio of RSS raised. The maximum flow of 160 mm is determined with the RSS/cement ratio of 0.75 (MX3). This may be due to the increment in the ratio of RSS/Cement.

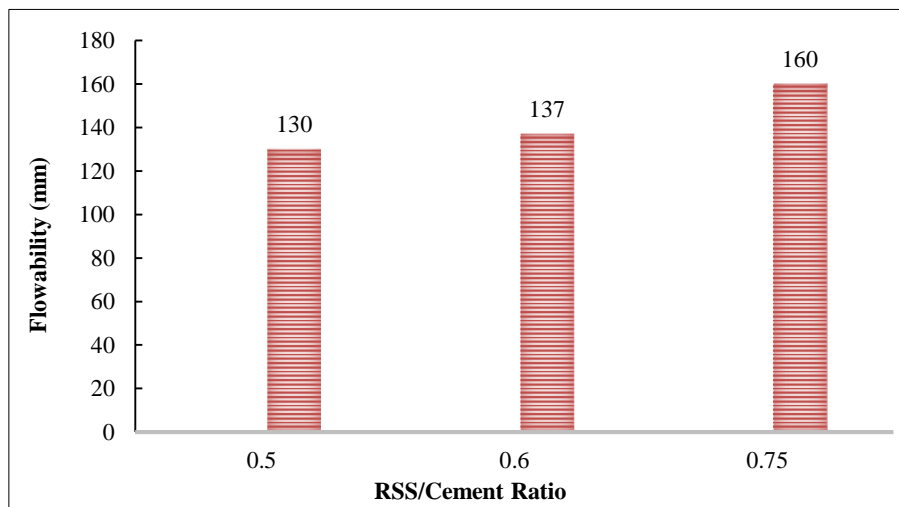


Figure 2. Flowability with various RSS/Cement ratios (Group I)

Effect of changing sand content (Group II)

Figure 3 mainly indicates the effect of changing sand ratio on flowability. This group has constant ratio 0.75 of RSS/cement and three ratios of sand/cement (3.0 (MX3), 4.5(MX4) and 6 (MX5)) have been studied. The results indicated that the flowability reduced as the ratio of sand/cement increased and the highest flowability of 160 mm was determined for MX3.

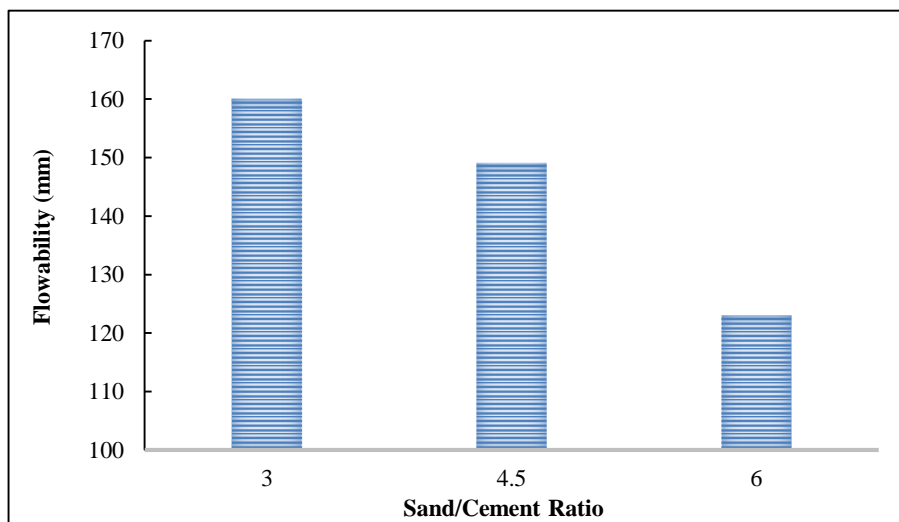


Figure 3. Flowability with various sand/cement ratios (Group II)

Effect of RHA (Groups III and IV)

Flowability of mixes that contained RSS and 10% of RHA (Group III (MX6) and Group IV (MX7)) are indicated in Figure 4. In addition, Figure 4 shows the flowability of the control mixes (0% RHA), i.e. MX2 and MX3. These groups (Groups III and IV) have a constant sand/binder ratio equals to 3 with different RSS/binder ratios as indicated in Tables 2 and 3. The results show different values of flowability for the two groups but the same behavior in which the control mixes (MX2 and MX3) have the highest values. However, Group IV has the highest value (136mm) and Group III has a value of (129mm) at 10% RHA.

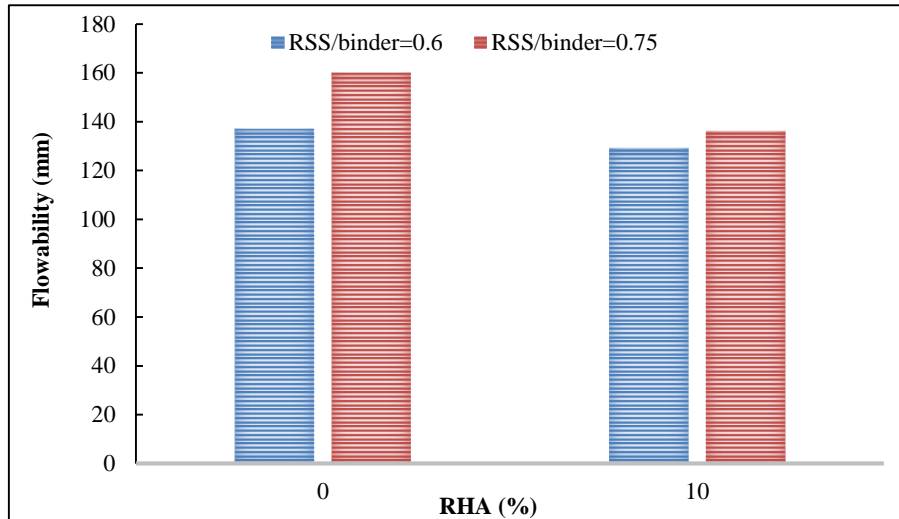


Figure 4. Flowability with various RHA and RSS/binder ratios

This behavior clearly indicates that the flowability reduced as the ratio of RHA increased for both RSS/binder ratios (MX6 and MX7). The results demonstrate that the water demand of mortars incorporating RHA increases with increasing amounts of RHA. This increase in water demand is due to the very large surface area of the particles of RHA, which have to be wetted. In general, to maintain the required flowability with no change in the water/cement ratio, the use of high-range water-reducing admixtures (HRWR, or superplasticizer) assist in this respect.

Effect of RHA (Group V)

Flowability of mixes that contained water and 10% of RHA (Group V (MX8 and MX9)) is shown in Figure 5. This group has constant sand/binder ratio equals to 3 with a constant water/binder ratio 0.75. The results show the highest value (198 mm) for control mix (0% RHA) and 179 mm for 10% RHA. This could be attributed, as mentioned in Groups (III and IV), to the very large surface area of RHA.

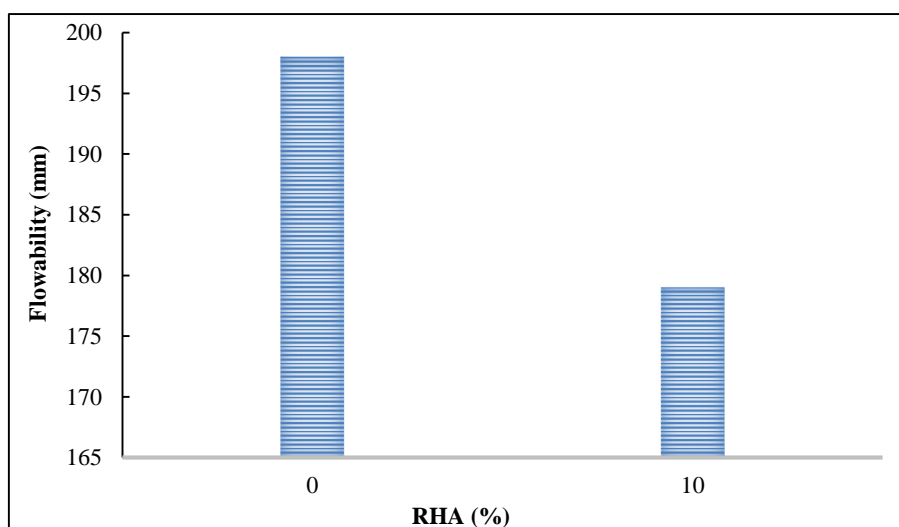


Figure 5. Flowability with various RHA ratio and water/binder ratio = 0.75

In the light of above, the flowability of mixes containing RSS and water has been demonstrated in Figure 6. This figure indicates that the highest value of flowability at MX8 (0% RHA and water) but the lowest value at MX7 (10% RHA with RSS). The relative flowability of mixtures prepared with RSS comparing to those prepared with water is indicated in Table 4. Both of them indicate differences in flowability for mixtures with and without RHA. But for 10% R

HA, the magnitude of difference is higher. These differences in flowability may be due to the use of RSS and RHA. Finally, using the RSS instead of water in all types of mixes leads to the reduction in flowability. This may be attributed to the ingredients existing in the RSS.

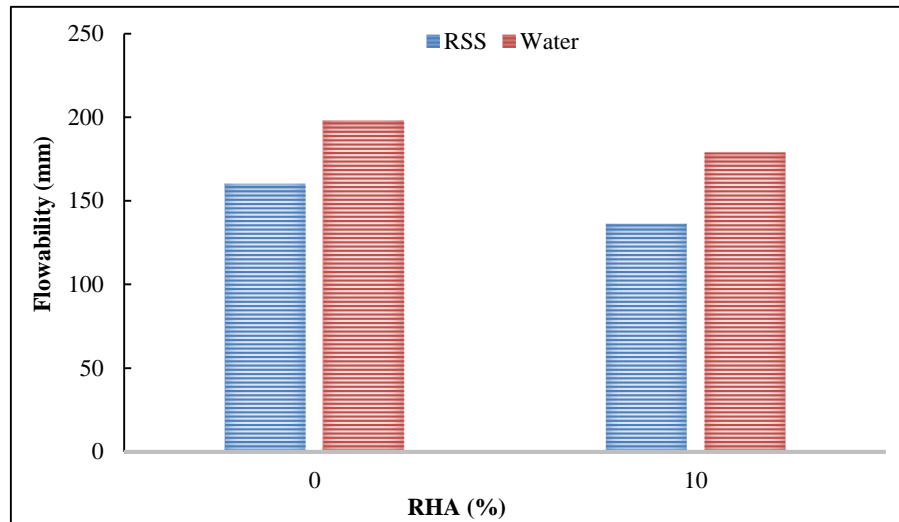


Figure 6. Flowability with various RHA, with water and RSS

Table 4. Flowability of mixtures with RSS and water

Mixes	RHA %	Relative flowability (%)
M3/M8	0	81
M7/M9	10	76

7.2. Compressive Test Results

The results of compressive strength for each group are summarized as below:

Effect of RSS (Group I)

Figure 7 demonstrates that the compressive strength with various RSS ratio. These mixes (MX1, MX2, and MX3) have one ratio (3) of sand /cement, 0% RHA and three ratios (0.5, 0.6, and 0.75) of RSS/cement. Mortar samples were examined for their compressive strength at 7, and 28 days. The figure indicates an obvious tendency in strength with RSS ratio, where the strength decreased as the RSS ratio increased and the maximum compression strength has been obtained with RSS/ cement content of 0.5 (MX1). This is consistent with the results of recent studies, which established that the strength drops as the w/c ratio rises [19-24]. The obtained results also indicated that the strength was improved sustainably with curing age treatment up to 28 days Figure 7.

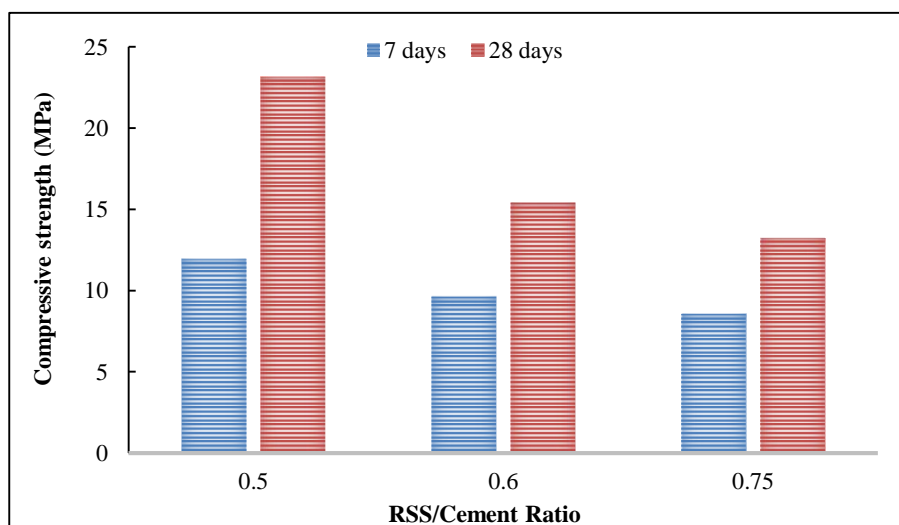


Figure 7. Compressive Strength with various RSS/Cement ratios

Effect of sand content (Group II)

Figure 8 stated how the compressive strength changed with different sand ratios at 7 and 28 days. Group II was prepared by three mixes that included one ratio (0.75) of RSS/cement and three ratios (3, 4.5 and 6) of sand/cement. The results indicated that the strength mostly decreased as the sand ratio increased. The higher strength has been achieved for the ratio of 3 sand/cement (MX3) at 28 days. This reduction in strength may be due to the increase in sand content.

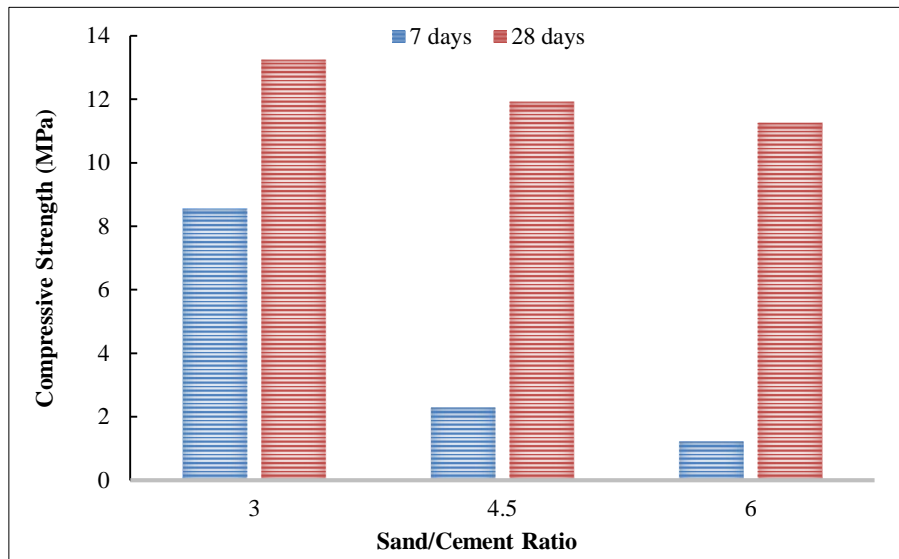


Figure 8. Compressive Strength with various sand/cement ratios

Effect of RHA (Group III and IV)

Figures 9 and 10 indicate the determination of the compressive strength with RSS and different ratios of RHA at 7 and 28 days. Two groups of mixes that had one ratio (3) of sand /binder and ratio of 10% RHA by the total weight of binder, were tested. Group III was arranged with a ratio of RSS/binder equals to 0.6 while Group IV was arranged with a ratio of 0.75 for RSS/binder.

Figures 9 and 10 obvious that mix made with 10% cement replacement by RHA performs better compressive strength than mix with no cement replacement (0% cement replacement). The optimum compressive strength was undertaken with RSS/Binder ratio of 0.6 at 28 days. This enhancement in compressive strength is may be due to the pozzolanic activity of RHA.

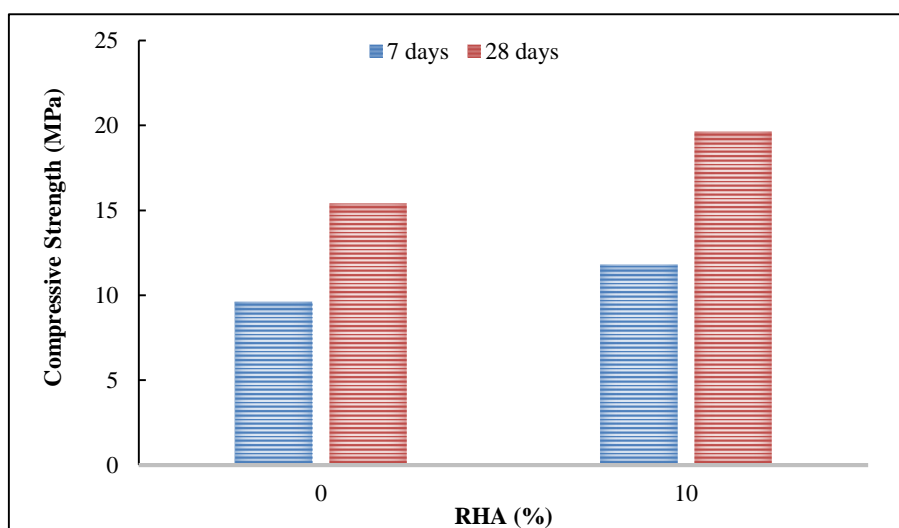


Figure 9. Compressive strength with various RHA replacement and RSS/binder ratio of 0.6

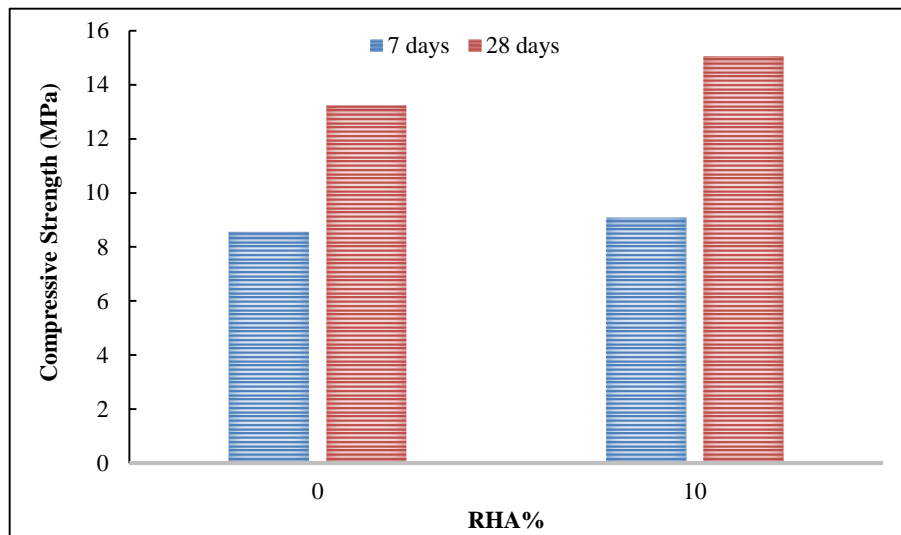


Figure 10. Compressive strength with various RHA and RSS/binder ratio of 0.75

Influence of RHA (Group V)

This group indicates how the strength of the mixes containing different RHA ratios at 7 and 28 days as indicated in Figure 11. These mixes have one ratio (3) of sand / binder, water/binder ratio of 0.75 and RHA 10% by weight of total binder. The results demonstrated a noticeable improvement in the strength for all samples that included RHA, and the highest strength of 11.37 MPa was determined with 10% RHA (MX9).

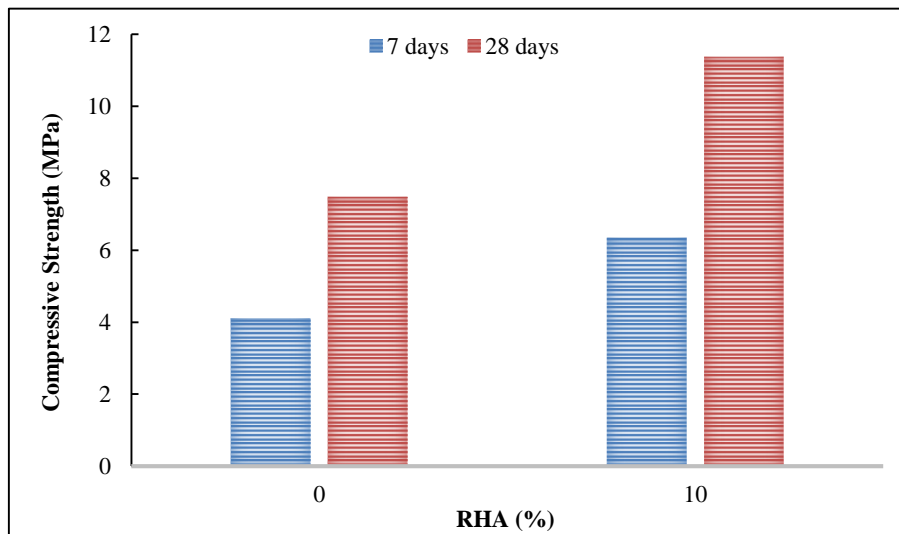


Figure 11 Compressive strength with various RHA and water/binder ratio (0.75)

Figure 12 indicates that the strength of the samples with water and RSS. The strength of the samples that included RSS was remarkably more than the samples with water. The relative strength of the mixes prepared with RSS comparing to those prepared with water has been indicated in Table 5. The strength of the samples that had RSS was remarkably more than the mixtures with water, and the relative strength ranged between 143-208 % at 7 days and 132-177 % at 28 days. This may be due to the interaction between the RSS and cement. In brief, the mixes with RSS show high compressive strength comparing with mixes with water in all ages (7 and 28 days).

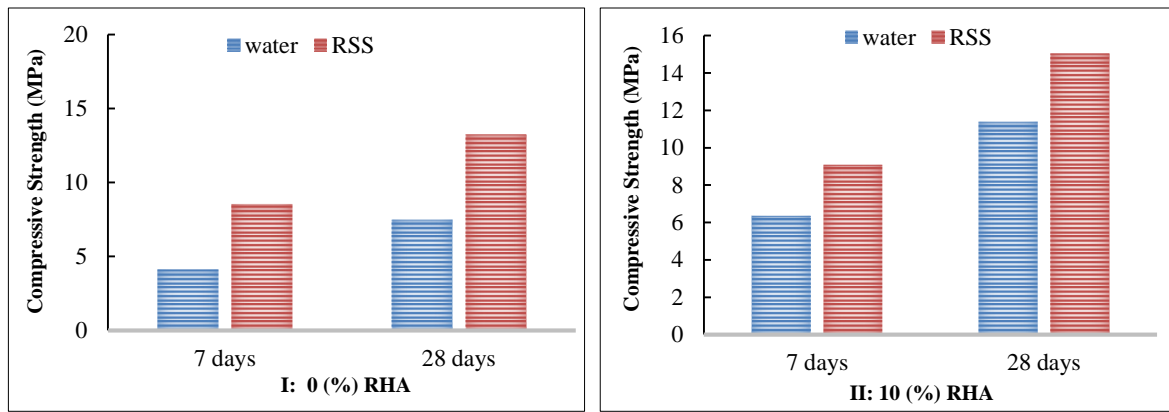


Figure 12. Compressive strength with both RSS and water

Table 5. Relative compressive strength (%) of mixtures with RSS in comparison to those prepared with water

Mixes	RHA (%)	Relative compressive strength (%)	
		7 days	28 days
M3/M8	0	208	177
M7/M9	10	143	132

7.3. Density Test Results

The results of density for each group of mixes are indicated in the following points:

Effect of RSS (Group I)

The density with various RSS ratios has been indicated in Figure 13. Group I has one ratio (3) of sand/cement, 0% RHA and three ratios (0.5, 0.6, and 0.75) of RSS/cement. Density was obtained for mortar samples at 28 days. The results demonstrated that the density decreased as the ratio of RSS raised. The highest density of 2377.9 kg/m³ was obtained for MX1. Both density and voids ratio have been mainly based on the ratios of water/cement and compaction; hydration degree, and are also dependent on other factors counting volume of entrapped air, aggregate type and grading, and porous characteristics of utilized materials. Consequently; the existing of voids in mortar decreases the density and accordingly decreases strength.

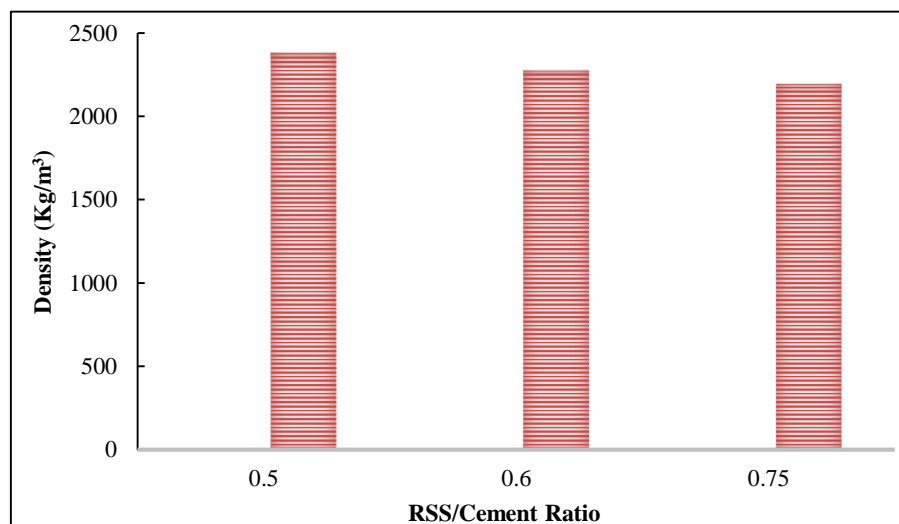


Figure 13. Density with various RSS/Cement ratios

Effect of sand content (Group II)

The effect of changing sand ratio on the density of hardened mortar has been indicated in Figure 14. Three mixes, which have a constant ratio (0.75) of RSS/cement and three sand/cement ratios (MX3, MX4 and MX5), were examined. The obtained results indicated that the density decreased as the ratio of sand /cement increased. The highest density of 2192.3 kg/m³ was obtained for MX3. This reduction in density could be attributed to the increase in sand content, and therefore non-homogeneity of the mix, so this led to increase the percentage of voids in mortar mix.

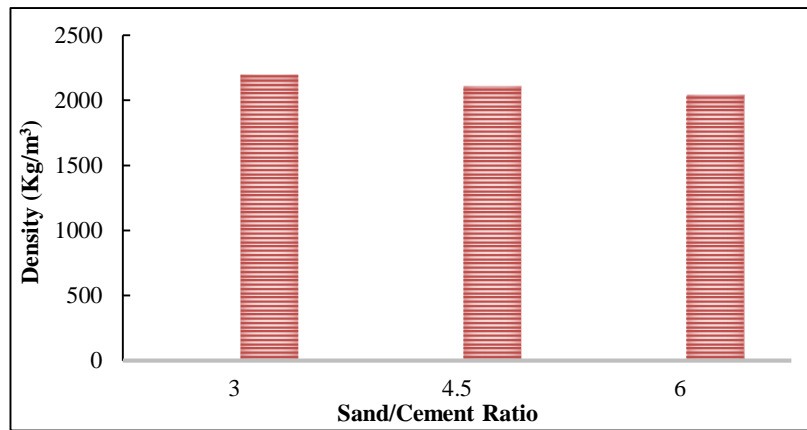


Figure 14. Density with various sand to cement ratios (Group II)

Effect of RHA (Groups III and IV)

The results of density for Groups III and IV are indicated in Figure 15. Group III has the highest density among other groups. For Groups III and IV, the results pointed out that the density increased when using 10% of RHA as a cement replacement comparing with the mix of no cement replacement (0% cement replacement) and the highest density was observed for RSS/Binder ratio of 0.6 (MX6). Furthermore, the obtained results indicated that the density mostly reduced as the ratio of RSS/binder increased.

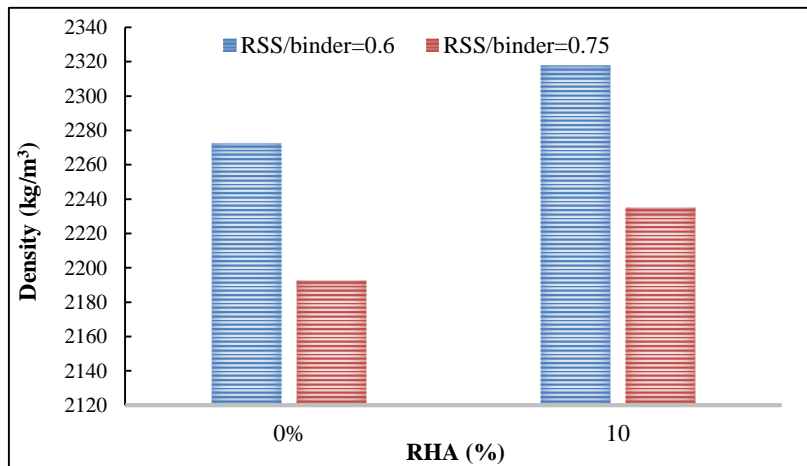


Figure 15. Density with various RHA and RSS/binder ratios

Effect of RHA (Group V)

Figure 16 shows the relationship between density and two ratios of RHA. Group V contained two mixes that have the same content of Group IV but with water. These results indicated that the addition of RHA (10% as a cement replacement) improved density more than that of the mix with no cement replacement.

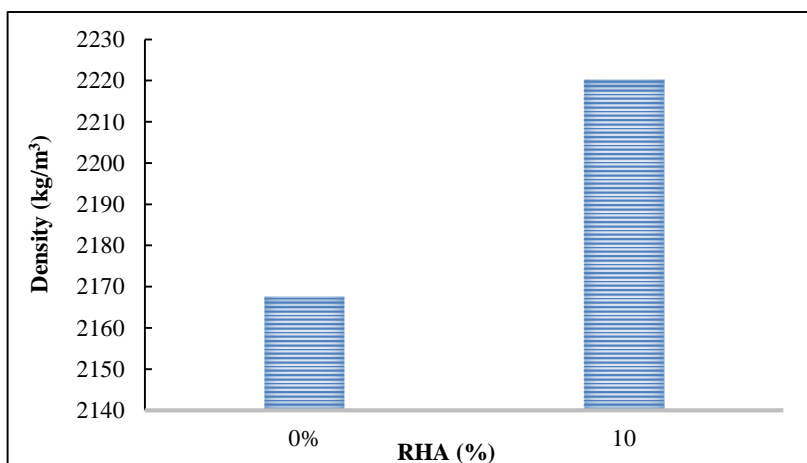


Figure 16. Density with various RHA ratios (Group V)

The density with RSS and water has been indicated in Figure 17, and the density is indicated in Table 6. No considerable variances were noted in density between mixtures had RSS and these mixes prepared with water as the density ranged between 100.7- 101%. In all mixes with RSS give more density than mixes with water. This may be due to the interaction between the RSS and cement which leads to the reduction in the percentage of voids in mortar mixes.

Table 6. Relative density (%) with RSS and those prepared with water

Mixes	RHA (%)	Relative density (%)
M3/M8	0	101
M7/M9	10	100.7

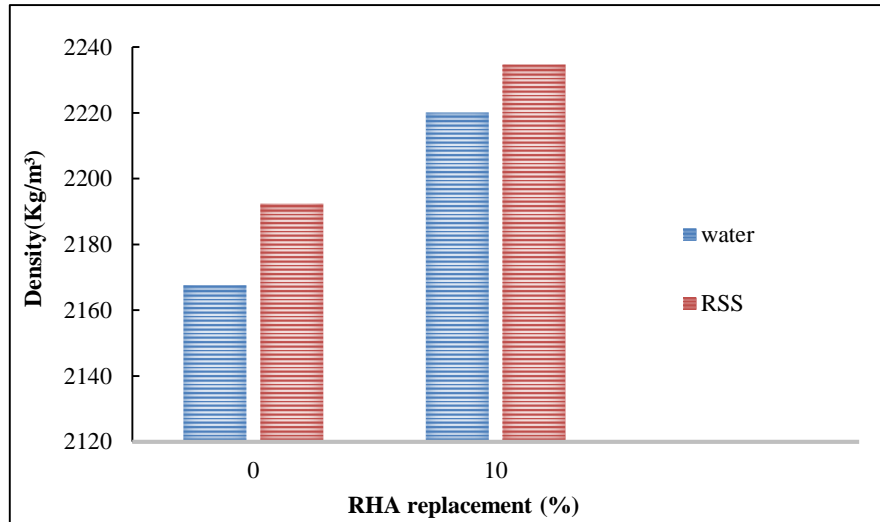


Figure 17. Density with both RSS and water

7.4. TWA Test Results

The results of TWA results for each group are:

Effect of RSS (Group I)

Figure 18 demonstrated the TWA values with various RSS ratios. Group I has three mixes (MX1, MX2, and MX3) that had a constant ratio of 3 sand/cement, and three ratios (0.5, 0.6; and 0.75) of RSS/cement. TWA was obtained for specimens at 28 days. This figure indicates a tendency in the TWA with RSS ratio, as TWA raised as RSS ratio raised and the minimum TWA was implemented for MX1.

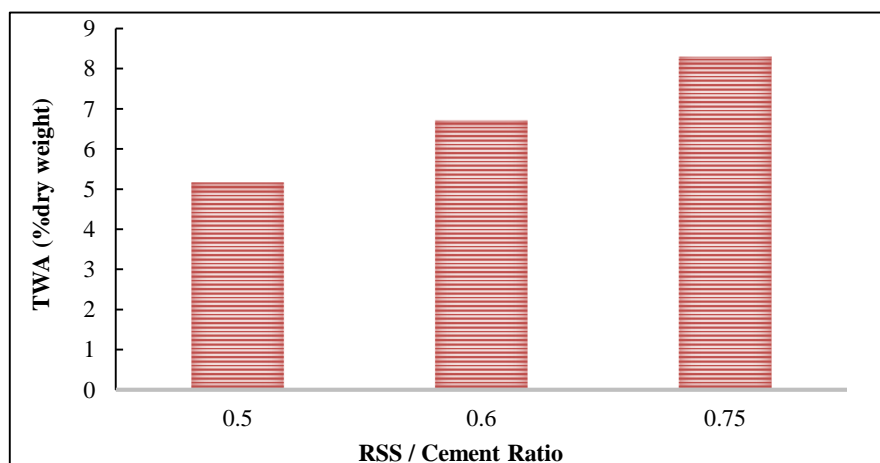


Figure 18. TWA with various RSS/cement Ratios

Effect of sand content (Group II)

TWA with various sand ratios is demonstrated in Figure 19. Three mixes that have one ratio (0.75) of RSS/cement and three ratios (3, 4.5 and 6) of sand/cement were examined. TWA was recorded for specimens at 28 days, and the average TWA was determined. However an obvious tendency in TWA has been noticed, as TWA raised as the sand content raised and the highest TWA of 11.87 % has been determined for MX5.

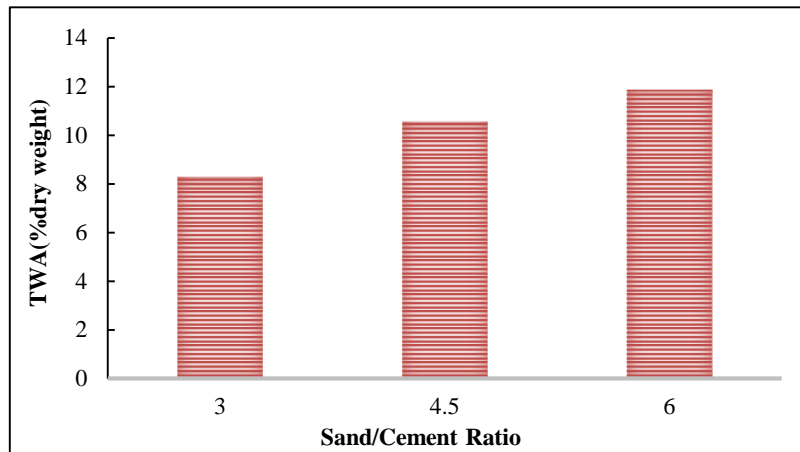


Figure 19. TWA with various sand/ cement ratios

Effect of RHA (Group III and IV)

Figure 20 illustrates the effect of TWA for two groups. For Groups III and IV, the results indicated that replacing cement with RHA at 10% of total binder weight decreased TWA comparing with the mix that has 0% RHA replacement (MX2 and MX3). However, the maximum TWA was noticed for RSS/binder ratio of 0.75 (MX3). Furthermore, TWA decreased significantly with RSS/binder is 0.75 at 10% RHA. This could be attributed for the RHA which absorbs water because of its large surface area.

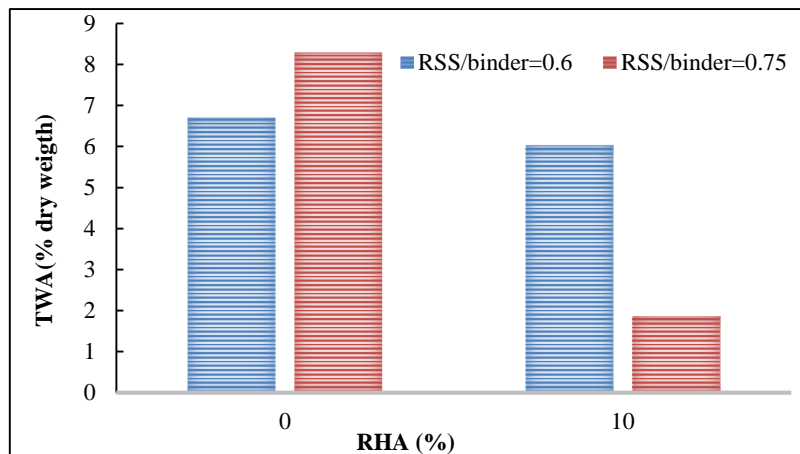


Figure 20. TWA with various RHA and RSS/binder ratio

Effect of RHA (Group V)

Group V has a constant ratio of sand/cement ratio of 3, water/binder ratio of 0.75 and ratio of 10% RHA by the total weight of binder as shown in Figure 21. TWA has been determined for samples at 28 days, and the average TWA has been found. The obtained results generally indicated that TWA values for mixes at 28 days with 10% cement replacement by RHA were comparatively less than those without RHA.

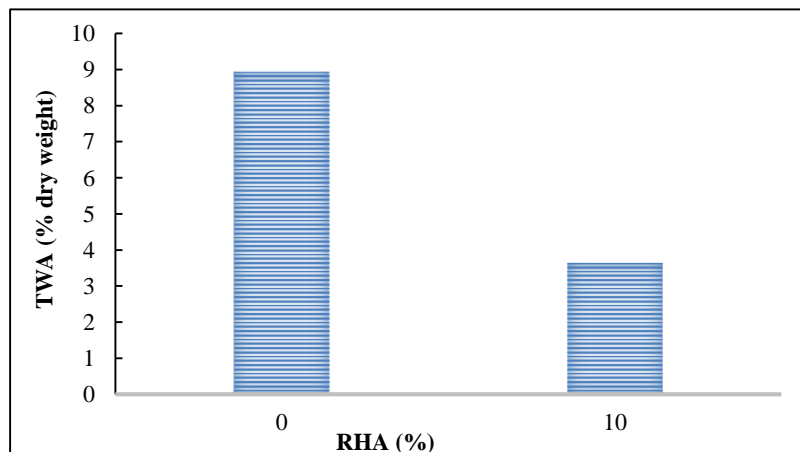


Figure 21. TWA with various RHA (GroupV)

Figure 22 indicated that changing of TWA with water and RSS, and the TWA has been indicated in Table 7. Both demonstrate no noteworthy differences in TWA between mixtures had RSS and these prepared with water at 0% (replacement). The TWA at 0% replacement was 92.8%. The TWA of the samples that contained 10% of RHA as a cement replacement for RSS mixes was observed less than the mixes having water. The TWA at 10% replacement was 51.4%. It was noticed that samples with RSS show TWA less than others with water for all mixtures with or without RSS. However, the TWA with 10% RHA is significantly less value than the mixes without RHA.

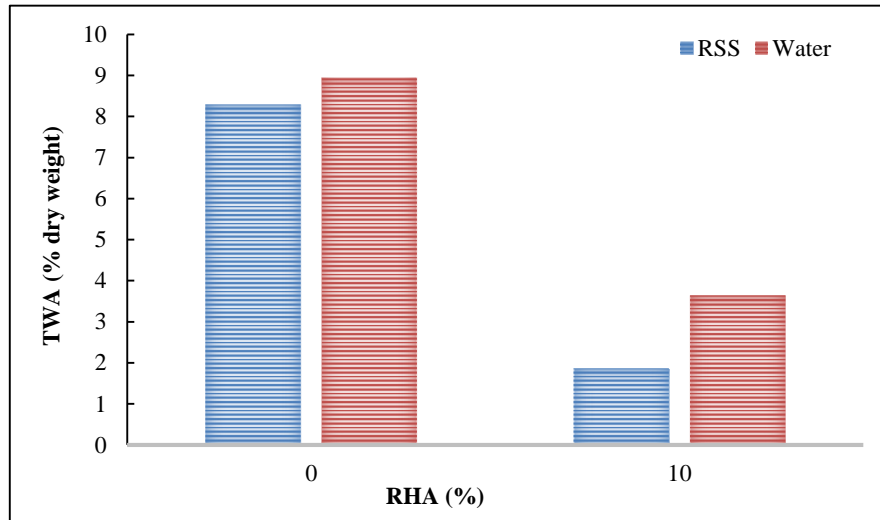


Figure 22. TWA with both RSS and water

Table 7. TWA (%) comparing with RSS to those prepared with water

Mixes	RHA%	Relative TWA (%)
MX3/MX8	0	92.8
MX7/MX9	10	51.4

All the results in this study and the behavior are similar to the findings obtained by [5, 6]; however, they used RSS with unprocessed fly ash instead of RHA.

8. Conclusions

The main points come up with this study could be summarized as:

1. Flowability: The highest value of flowability is 198mm for Group 5 (MX8). In addition, this value is 160mm for Group I (MX3) and Group II (MX3). Whereas, the flowability is reduced as using 10%RHA instead of a cement for Groups III and IV. Similarly, the flowability decreases for Group V with 10% RHA.
2. Compressive strength: This characteristic has been influenced differently with each group of mix as indicated below:
 - As the ratio of RSS increases, the compressive strength for Group I decreases but the highest value for this group at 0.5 ratio of RSS/Cement (MX1) at 28 days.
 - Approximately, the same behavior is a reduction in compressive strength for Group II at 7 and 28 days. However, the highest value of this group at 3 ratio of sand to cement (MX3) at 28days.
 - The optimum compressive strength was obtained with 0.6 ratio of RSS/binder (MX6) at 28 days for Groups III and IV. In addition, the strength with 10% cement replacement by RHA has higher value than mix with no cement.
 - The highest strength of 11.37 MPa was obtained for Group V with 10% RHA (MX9) at 7 and 28 days. Additionally, the compressive strength of the mixes that had RSS has remarkably more than the samples with water, and the strength ranged between 143-208 % at 7 days and 132-177 % at 28 days.
3. Density: This character has a specific behavior for each group as following:
 - For Group I, the results indicated that a reduction in the density as the ratio of RSS increased. The highest density of 2377.9 kg/m³ was noticed for the mix M1.

- For Group II, the results indicated that the density decreased as the sand/cement ratio increased. the greatest density of 2192.3 kg/m³ was noticed for the mix M3.
 - For Groups III and IV, the results indicated that the density increased as the 10% of RHA used as a cement replacement comparing with the mix of no cement replacement (0% cement replacement) and the highest density was noticed that the mix with RSS/Binder ratio of 0.6 (MX6). Moreover, the results indicated that the density mostly decreased as the ratio of RSS/binder increased.
 - For Group V, the results revealed that the addition of RHA (10% as a cement replacement) improved density more than that of the mix with no cement replacement. The density of 2220.12 kg/m³ was obtained for mix with 10% RHA (MX9). Moreover, there is no clear variances in density between mixes had RSS and these prepared with water when the density ranged between 100.7- 101%.
4. TWA: Similar to previous character, the TWA depends on each group as following:
- For Group I, TWA increased as RSS ratio increased and the minimum TWA was obtained for M1.
 - For Group II, TWA raised as the ratio of sand increased and the highest average TWA of 11.87 % for M5.
 - For Groups III and IV, the average results indicated that changing cement with 10% RHA (MX6 and MX7) decreased TWA in comparison with the control mixes (MX2 and MX3). However, the maximum TWA was noticed for the mix with RSS/binder content of 0.75 (MX3). Furthermore, TWA decreased as RSS ratio increased for all samples with RHA.
 - Group V, the results generally indicated that TWA values for mortar mixes at 28 days with 10% cement replacement by RHA were comparatively less than those for the control mix. In addition, no important variations in TWA between samples had RSS and those prepared with water at 0% replacement. The relative TWA at control mix was 92.8%. The TWA of the samples that contained 10% of RHA as a cement replacement for RSS mixes was observed less than the mixes have water. The relative TWA at 10% replacement was 51.4%.

9. Conflicts of Interest

The authors declare no conflict of interest.

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