Use of Rice Husk Ash as Strength-Enhancing Additive in Lightweight Cementitious Composite Mortars

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Abstract. This paper investigates the properties of rice husk ash (RHA) produced by using a ferro-cement furnace. The effect of RHA percentage on lightweight composite mortar consistency, initial and final setting time, plastic and dry set density, flexural and compressive strength were investigated. Incorporation of RHA in lightweight mortar increased water demand. The effect of early (7 and 14 days) and long term curing ages (90 and 120 days) on the mechanical strength properties of lightweight composite mortars with RHA were also analysed. Mortar samples show strength reduction of 10.6% and 8.57% compared to the control mix at early curing ages of 7 and 14 days, respectively. RHA mortar gave excellent improvement in strength for 20% replacement (18.85% and 21.69% increment compared to the control mix at long-term curing of 90 and 120 days), and up to 25% of cement by weight be valuably replaced with RHA without adversely affecting the strength. Increasing replacement ratio of RHA enhanced the strength of blended mortar compared to low utilization ratio of RHA and control OPC mixtures.

1. Introduction
The usage of lightweight aggregates in mortar is increasing remarkably due to energy and safety reasons. Lightweight cementitious composite mortars (LCCM) are known in which the desired weight reduction as compared with normal weight mortar is achieved by the use of lightweight aggregates. The important factor for energy saving (heat insulation) in buildings is the used construction materials and their thermal properties. Nowadays, usage of lightweight cementitious composite mortars produced from different lightweight aggregates is becoming highly widespread especially for energy saving in buildings. For the improvement of the properties of lightweight cementitious composite mortars or the construction cost to be economic, admixtures are added with the cement mix. These are either naturally occurring compounds or chemicals produced in industrial process. Most of the admixtures are pozzolans. A pozzolan is a powdered material, which when added to the cement in a mortar mix reacts with the lime, released by the hydration of the cement, to created compounds which improve the strength or other properties of the mortar [1, 2]. According to ASTM [3] after chemical analysis if the sum of Iron oxide (Fe2O3), Silicon dioxide (SiO2) and Aluminum oxide (Al2O3) is more than 70% then the material could be declared as a Pozzolanic material [4]. It is observed by many researchers that there is an increase of compressive strength of mortar with the use of pozzolanic materials. The increase in compressive strength could be attributed to the reduced water content, the filler effect, and the higher pozzolanic reaction [4]. The fine fineness of pozzolans had a greater pozzolanic reaction and the small particles could also fill in the voids of the mortar mixture, thus increasing the compressive strength of the mortar [5]. The use of industrial and biogenic wastes in
concrete as supplementary cementing materials is the present vital issue to obtain a sustainable environmental solution, save energy and natural resources. Some of the commonly used supplementary pozzolanic and cementing materials are rice husk ash (RHA), silica fume, ground granulated blast furnace slag, fly ash and ash from timber etc [6]. Supplementary cementitious materials may considerably improve the strength and durability of concrete [7, 8]. Rice husk is one of the most widely available agricultural wastes in many rice producing countries around the world. It is assumed that about 500 million tons of paddy is produced in the world annually. Rice husk is the outer covering of this paddy and the grain of white rice with high concentration of silica [9, 10]. Generally this silica concentration is more than 80-88%. The ash obtained by burning this rice husk is known as RHA. As a waste material, rice husk is produced in agricultural and industrial processes. After incineration, only about 20% weight of rice husk are transformed to RHA [11]. A number of relatively new supplementary cementitious materials, such as rice husk ash, sewage sludge ash, and oil shale ash, have undergone extensive research [12, 13]. These wastes can be found as natural materials, by-products or industrial wastes; these materials are also obtained with requiring low cost, energy and time. Unfortunately, having technical benefits, most of those wastes are dumped into environment without any commercial return [6]. A rising trend towards the use of waste material in mortar as supplementary cementitious materials has been observed in the construction industry. RHA as an agricultural by-product has already been proved as pozzolanic material [14, 15, 16, 17]. Nowadays, more attention is now given to use this pozzolans in cementitious mortar applications due to the improving the properties of the mortar. Thus, in recent decades, RHA has been used as OPC replacement material in concrete industries [18, 19]. The utilization of RHA in ternary blend (OPC, RHA and fly ash) produces better mortar strengths at the low replacement level of RHA. With the low replacement of up to 20% of pozzolan, the mortar containing these pozzolans reduces porosity [20]. Solution of disposal problem of these wastes and production of economic concrete could be assured by their proper consumption. Hence, utilization of RHA in concrete is not only a cement saving step but also has technical/engineering benefits [6, 21]. Turkey is one of the rice producing countries even its production rate is slightly low and per capita rice consumption is relatively higher than that in any other countries. In rice producing regions of Turkey, rice husks after production are becoming a local natural waste material. These waste materials have a limited use in industrial areas in Turkey unlike other countries. Rice husk ash consists of non-crystalline silicon dioxide (SiO₂) with high specific surface area and high pozzolanic reactivity. Thus, due to growing environmental concern and the need to conserve energy and resources, utilization of industrial and biogenic wastes as supplementary cementing materials [6] has become an integral part of cementitious construction materials.

Due to the pozzolanic reactivity, RHA is used as supplementary cementing material in mortar and has demonstrated significant influence in improving the mechanical and durability properties of mortar. The behaviour of RHA as supplementary cementing material in lightweight aggregated cementitious composite mortars is a new research area and there is a very limited knowledge about the subject. Its economical and technical advantages to use in LCCM combinations should be well analysed and evaluated.

2. Experimental work

2.1. Materials used in the research

Ordinary Portland Cement (OPC) conforming to ASTM C 150 Type 1 (42.5 N/mm²) was used for this study. The chemical composition of the cement is given in Table 1. The Bogue compound composition of the cement was calculated according to ASTM C 150 [22] and is also given in Table 1. The cement was tested for its mineral content and the loss on ignition using the X-ray Fluorescence (XRF) analysis. The average particle size distribution was determined by laser particle analyzer. The specific gravity of cement was determined according to the British Standard (BS 1377:Part 2) using the small pycnometer method. The fineness of the cement was determined by conducting the Blaine surface area test according to ASTM C 204-94a and given in Table 2. Pumice aggregate used in this
experimental study was supplied from the location of pumice Mining Quarry in Kayseri Region, Centre of Turkey. Kayseri pumice aggregate (KPA) obtained from the quarry was only crushed by a primer crusher and then screened into 0–3 mm as fine aggregate form. The fine pumice aggregate was then visually analysed by a microscope and the pumice particulates were observed as mostly rounded shape in an acceptable scale. This situation is thought to be help to mortar strength. Pumice aggregate is a natural lightweight aggregate that is formed by the sudden cooling of molten volcanic matter. Pumice is formed during the volcanic eruption of viscous magma, mostly siliceous and rich in dissolved volatile constituents, especially water vapour.

Hydrated Powder Lime (HPL) used in this work was a commercial product in Turkey. The hydrated lime in powder belongs to the class CL90 according to EN 459-1. The particle size distribution of HPL for d(0.1) was 1.15 μm, for d(0.5) and d(0.9) were 2.33 μm and 4.54 μm, respectively. HPL was used in the batches as the aim of pH stabilizing additive. Its bulk dry density value was 780 kg/m³. Hydrated lime is a soft, white, crystalline, very slightly water-soluble powder as Ca(OH)₂, obtained by the action of water on lime. It is chiefly used in mortars, plasters, and cements. The chemical composition of HPL is given in Table 1.

The calcite used in the composition of mortars was also a commercial product in Turkey. The calcite used in this experimental program was a white powder form obtained by grinding from calcite minerals. The calcite material was as a powder calcite filler (PCF) material in mixture combinations. Its maximum particle size was 500 μm and its bulk dry density value was also 1280 kg/m³. The chemical composition of PCF is given in Table 1.

| Major element | OPC (%) | KPA (%) | HPL (%) | PCF (%) | RHA (%) |
|---------------|---------|---------|---------|---------|---------|
| SiO₂          | 20.83   | 66.80   | < 1.3   | 0.05    | 87.8    |
| Al₂O₃         | 5.48    | 14.75   | 0.4 – 0.8 | 0.10    | 0.46    |
| Fe₂O₃         | 3.94    | 2.85    | < 0.3   | 0.04    | 0.26    |
| CaO           | 61.56   | 2.95    | 70.8    | 55.20   | 1.37    |
| Na₂O          | 0.21    | 3.95    | < 0.2   | 0.03    | 1.22    |
| K₂O           | 0.74    | 2.75    | < 0.2   | 0.02    | 3.44    |
| MgO           | 2.33    | 0.80    | < 0.8   | 0.55    | 0.42    |
| LOI           | 1.88    | 4.15    | -       | -       | 3.09    |

Rice straw and husk are composed of both organic and inorganic matter. Rice husk contains 75-90% organic matter such as cellulose, lignin, hemi cellulose, some proteins and vitamins while the major component of inorganic minerals is silica, alkalis and trace elements [4, 23]. The actual composition of rice straw and husk varies with the type of paddy, inclusion of bran and broken rice in the husk, geographical factors, crop season, samples preparation and relative humidity [24, 25]. The rice husk used in this research was collected from agricultural rice producing fields in Black Sea Region of Turkey. It was then burned in the laboratory by using a furnace, with incinerating temperature not exceeding 700°C. The incineration was actually executed with controlled temperature in order to establish the optimum burning temperature and burning time according to burning condition of rice husks [26, 27]. A fire source was maintained under the furnace for around 10 minutes, after which the husks slowly burned for more than one day. The ash was left inside the furnace to cool down before it was collected [28]. The ash was then grinded using Los Angeles mill to produce finer ash for 90, 180, 270, 360 minutes. The RHA ground for 90 minutes was only tested for
particle size analysis and surface area to show the effect of grinding time on the average particle size and specific surface area. Loss Angeles mill was used to grind the ash. This machine consists of a rotating drum with an opening on top of it, inside the drum there are 40 mild steel rods (10 mm diameter and 500 mm length) for grinding the ash. The mill can hold up to 5 kg of ash and its amount was kept constant each time the mill was used. The milling time was adjustable in the range of (90-360 minutes) according to the required fineness [28]. Average particle size of RHA was determined as the value of 65.7 μm ground for 90 minutes’ time. The average particle sizes of RHA more ground materials were 32.8 μm, 19.6 μm and 12.8 μm for 180, 270 and 360 minutes, respectively. The XRD analysis was performed to determine the silica form of the produced RHA powder samples. RHA samples were scanned by electron microscope to show the multi layered structure and micro porous surface of RHA particles. The chemical composition of RHA is also given in Table 1.

Table 2. Mechanical and physical properties of OPC

| Property                        | Value  |
|--------------------------------|--------|
| Specific gravity (g/cm³)        | 3.12   |
| Blaine specific surface (cm²/g) | 3254   |
| Initial setting time (min)      | 146    |
| Final setting time (min)        | 198    |
| Volume expansion (mm/m)         | 2.87   |
| Compressive strength (MPa)      |        |
| 2 days                          | 14.8   |
| 7 days                          | 27.4   |
| 14 days                         | 35.3   |
| 28 days                         | 43.4   |

Cellulose ethers are additives which control to a large extent the rheology of a cement mortar. In a complex matrix of this multiphase blend they have an impact on the yield point and the shear thinning behaviour [29]. Cellulose ether is an indispensable component of a cement mortar formulation. This highly functional additive helps to adjust the performance profile of the mortar at various levels. The solubilized cellulose ether in the mortar matrix determines to a large extent its rheological properties and subsequently the workability of the mortar. The cellulose ethers preferred in dry-mix mortar application are hydroxypropyl methyl cellulose (HPMC) or hydroxyethyl methyl cellulose (HEMC). In this research program, a commercially available HEMC in Turkey was used for all mixtures to provide sufficient water retention to the mortar so that the cement can set and develop strength before it dries out. It was a nonionic cellulose ether that provides many of the same benefits as other methylcellulose derivatives, such as the ability to efficiently thicken and provide water retention. It was a white powder form as a very fine size; its etherification property was very high. Its level of viscosity was 150000 mPa.s according to Höppler. The water solution appears strong pseudoplastic and provides excellent shear viscosity. It is mainly used for binders, protective colloid, thickeners, stabilizers, and emulsifier. It is also dissolved readily in cold water, not the hot. The water was regular tap water.

2.2. The mortar mixture proportioning

The design of the mortar’s composition is given in Table 3. Mixture proportioning was carried out according to the mix design methodology currently prescribed in EN 998-1 and the relevant standards. Ten mortar mixes were made and analysed in order to evaluate the potential interest of using rice husk ash on cement based lightweight mortars. In all mixes the amounts of binder (cement + rice husk ash) ratio were kept constant as 1% by volume throughout the study. Furthermore, the amounts for the rest of total aggregate in the mixes were also kept constant as 5% by volume throughout the research. One mortar mixture (M1) was analysed as a reference mortar without using any RHA. This batch actually was undertaken to determine mean compressive strength, mean flexural strength and unit weight values of mortar mixtures by effect of KPA, HPL and PCF mixing conditions.
Table 3. Mixture constituents and designation for testing mortar

| Mix | OPC (%) | KPA (%) | HPL (%) | PCF (%) |
|-----|---------|---------|---------|---------|
| M1  | 1       | 5       | 0.0     | 1.5345  |
| M2  | 1       | 5       | 3.0     | 1.5621  |
| M3  | 1       | 5       | 5.0     | 1.6103  |
| M4  | 1       | 5       | 8.0     | 1.6586  |
| M5  | 1       | 5       | 10.0    | 1.7138  |
| M6  | 1       | 5       | 15.0    | 1.8241  |
| M7  | 1       | 5       | 18.0    | 1.8690  |
| M8  | 1       | 5       | 20.0    | 1.9414  |
| M9  | 1       | 5       | 22.0    | 2.0207  |
| M10 | 1       | 5       | 25.0    | 2.1345  |

The water demand for each mix was determined by the flow table test according to ASTM C 109 in order to provide the standard workability for all mixes. The total binder content was 224 kg/m³, HPL and PCF content were both 62 kg/m³, KPA content was 425 kg/m³ for all mixtures throughout the research. The water/cement ratios were changed from 1.5345 to 2.1345 based on the cement/aggregate ratios. The total mixing time was 5 minutes then the samples were casted and left for 24 hours. After that, samples were demoulded and placed in wet surface curing condition up to first 3 days and then left drying in a normal room condition until the testing time at the age of 7, 14, 28, 90 and 120 days. In this study, the influence of RHA for the level of replacement was studied simultaneously, 3, 5, 8, 10, 15, 18, 20, 22 and 25% of cement was replaced with RHA. The properties of fresh mortar samples, i.e. consistency and fresh or plastic set density were studied, then, the flexural and compressive strength at the age of 7, 14, 28, 90 and 120 days were investigated. Tests on compressive strength and flexural strength were carried out on prismatic specimens in order to evaluate the mechanical properties of the mortars. Specimens left in the casting room for 24 hours then moved into the wet surface curing condition up to first 3 days in a guarded moisture cup. Then all specimens moved into open and dry cup for curing in normal room conditions until the time of testing. The flow table test was conducted to evaluate workability and consistency of mortar mixtures. Compressive and flexural strength tests were conducted to relevant EN standards on 40x40x160 mm prismatic test samples; compressive and flexural strength were determined as the average value taken from 3 specimens as per the relevant standards. However, when the standard deviation was increased to a value which more than 0.2 MPa, an additional specimen was tested and the average value of the closest 3 specimens were determined.

3. Experimental work

3.1. Flow and water demand

The water content and flow values were tested at the stage of mortar preparation. The corresponding water to cement ratio (W/C) is given in Table 3. The flow tests confirmed the possibility of producing mortar relatively with a high W/C. The water/cement ratios were changed from 1.5345 to 2.1345 based on the RHA replacement amounts. Water demand was observed from the results of flow table test. The standard consistency values of each batches according to % RHA ratios is given in Figure 1. Evaluating the Figure 1, the water demand is increased by 2.03 % and 40.41% for 3% and 25% RHA by weight of cement as replacement binder, respectively. This demand pattern is increasing for increased of RHA addition. This is due to the high fineness and porous surface of RHA.
3.2. Initial and final setting time

The term setting of cement is used to describe stiffening of cement paste. When the cement is mixed with water, the three main compounds of cement i.e., tri-calcium silicate (C₃S), tri-calcium aluminate (C₃A) and di-calcium silicate (C₂S) react with water. C₃S hydrates more rapidly and develop early strength, generates heat more rapidly and has less resistance to chemical attack, whereas C₂S hydrates and hardens slowly and it adds to the ultimate strength and provides more resistance to chemical attack. C₃A is fast reacting and large amount of heat generates and cause initial setting. The phenomenon of changing from fluid state to a rigid state is called setting of cement [4, 30]. Pozzolanas will exhibit cementitious reactions only in the presence of added lime. The setting reaction takes place by the partial dissolution of the pozzolana in water to produce silica in solution. The dissolved silica then reacts with the calcium hydroxide to form CSH gel [31]. As indicating the rice husk ash is a high pozzolanic material, mortars with RHA – lime are produced by adding water to a mixture of lime, aggregate and RHA. The reaction between the RHA and lime to produce the CSH gel produces a hydraulic setting mortar. The setting times of the lime-RHA mortars are variable. The initial setting commences between one and two hours after mixing, and the final setting occurs four and five hours after mixing. In the absence of the pozzolana, the mortar will harden very slowly by reaction with carbon dioxide. In cementitious mortars with RHA, the lime necessary for the setting reaction comes mainly from the hydration of the C3S in the Portland cement as stated by [31].

Vicat apparatus was used to estimate initial and final setting time of fresh mortar samples at normal consistency. This test was performed according to BS 12-1971. Initial and final setting times are given in Table 4. Initial setting time varied from 117 to 154 minutes based on the RHA replacement amounts. A similar variation was also observed for final setting time of all batches. Setting time of all batches was ranged between 3.60 and 4.35 hours based on the RHA replacement amounts, too. In general, the test results showed that the inclusion of RHA increased both setting times.

| Mix | Initial setting (min) [not less than the value] | Final setting (h) [not less than the value] | Standard Consistency (mm) | Plastic set density (kg/m³) | Dry set density (kg/m³) | Compressive Strength at 28 days (N/mm²) |
|-----|---------------------------------------------|-------------------------------------------|---------------------------|---------------------------|-------------------------|------------------------------------------|
| M1  | 117                                        | 3.60                                      | 165                       | 1118                      | 815                     | 2.24                                     |
| M2  | 121                                        | 3.68                                      | 167                       | 1125                      | 815                     | 2.24                                     |
| M3  | 124                                        | 3.75                                      | 168                       | 1137                      | 817                     | 2.25                                     |
| M4  | 128                                        | 3.82                                      | 170                       | 1149                      | 817                     | 2.26                                     |
| M5  | 134                                        | 3.90                                      | 172                       | 1162                      | 819                     | 2.27                                     |
| M6  | 138                                        | 3.98                                      | 176                       | 1189                      | 821                     | 2.29                                     |
| M7  | 141                                        | 4.08                                      | 179                       | 1200                      | 821                     | 2.31                                     |
| M8  | 145                                        | 4.12                                      | 182                       | 1217                      | 823                     | 2.33                                     |
| M9  | 148                                        | 4.22                                      | 184                       | 1236                      | 824                     | 2.31                                     |
| M10 | 154                                        | 4.35                                      | 189                       | 1263                      | 826                     | 2.29                                     |
3.3. Plastic and Dry Set Density
Due to slightly increase W/C, the investigated mortars demonstrated increase in both plastic and dry set density values (Table 4). The plastic set density of tested LCCM mortar samples were varied 1118 kg/m$^3$ to 1263 kg/m$^3$ based on the percentage of RHA ratio. Similar increasing trend was also observed for the dry set density values ranging from 815 kg/m$^3$ to 826 kg/m$^3$. The research results show observationally that increasing the density of LCCM mortar as expected is getting more resistant. On the other hand, as the plastic set density value of LCCM mortar at the highest RHA ratio of 25% is higher with the percentage of 12.97 in comparing the control mixture value, its dry set density is only higher 1.35%, too.

3.4. Flexural strength
The flexural strength of the mortar mixes is shown in Figure 2 and 3. An inspection of Figure 2 and 3 indicates that a linear relationship exists between the flexural strength and the RHA replacement amounts. The test results showed that flexural strengths of all batches increase depending on the increase in the curing time. Maximum flexural strength value was recorded as a value of 0.50 MPa with batch of 20% RHA replacement at 120 curing days. The flexural strength of the mix containing 20% of RHA by weight of cement is 25% higher than the control mix, which may be due to the better compaction and homogeneity of the powder fine particulates in mortar structure. It can also be noted that the use of more than 20% of RHA replacement slightly decreases the improvement in flexural strength, which may be due to physical difficulties in providing a homogeneous distribution of the powder fine particulates within the mortar mix.

![Figure 2](image1.png)
**Figure 2.** Effect of RHA replacement (0%-10%) ratio on flexural strength of LCCM samples.

![Figure 3](image2.png)
**Figure 3.** Effect of RHA replacement (15%-25%) ratio on flexural strength of LCCM sample.

3.5. Compressive strength
Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. It provides data of force vs. deformation for the conditions of the test method. The compressive strength of samples was tested according to ASTM C109. ASTM C618 specifies that fly ash mortar should have a strength activity index of at least 75% of the control mortar at the age of 7 or 28 days when the fly ash is used to replace Portland cement at the rate of 20% by weight of binder [32]. The tested compressive strength values of all mortar batches at 7 days to 120 days curing time are presented in Figure 4 and 5 based on percentage of RHA replacement by weight of cement. The results showed that at early ages the strength was comparable. The strength of mortar with RHA was shown lower strength than that of OPC samples at 7 and 14 days. At a same RHA percentage, a gradually increasing strength was observed throughout the research. The compressive strength development at various RHA percentages by weight of binder in mortar samples is given in between Figure 6 and 8.
The effect of RHA amount as a substitute for cement on compressive strength of LCCM mortar samples was found that the strength varies as a function of curing time. At the age of 7 and 14 days early curing, the compressive strength of LCCM mortar samples shows an acceptable decreasing tendency depending on the amount of RHA by weight of cement (Figure 6). RHA ratio increases, the compressive strength is decreasing. This change in strength reduction is 10.6% for 25% RHA ratio compared to control mortar sample value at 7 days curing. It was also observed that this change in strength reduction is 8.57% at 14 days of curing at the same RHA ratio. The test results showed that at 7 and 14 days of early curing times, the compressive strength values obtained for all of RHA utilization rates provide the strength value of over 90% of the compressive strength of the same curing time for the control sample. In this case, the strength index limit values specified in ASTM C618 standards for fly ash shows that easily achieved. Even the highest rate of 25% RHA used in experimental studies, it was observed that LCCM samples show providing the strength requirement of 89.94 and 91.43% for the control samples at 7 and 14 days of curing time, respectively.

Compressive strength values of mortar samples are grouped into 4 different categories in EN 998-1 standard at 28 days of curing time condition. These are; CS I class (0.4 – 2.5 N/mm²), CS II class (1.5 – 5.0 N/mm²), CS III class (3.5 – 7.5 N/mm²) and CS IV class (≥6 N/mm²). As evaluating the
compressive strength values of LCCM mortar samples based on the prescribed categories in EN 998-1 standard, it was observed that the compressive strength values up to 20% RHA by weight of cement at 7 days curing ensure the foreseen the strength of 1.5 N/mm² for CS II class and the strength values drop CS I class over the 20% RHA by weight of cement, too. On the other hand, foreseen the strength of 1.5 N/mm² for CS II class was ensured for all RHA utilization ratios at 14 days curing days. As it was evaluated the 28-day curing period as a normal setting time of cement, in contrast to the declining trend seen in the early strength, an increase on the compressive strength of LCCM mortar samples up to 20% RHA by weight of cement at 7 days curing was observed (Figure 7). Declining trend on strength was again seen over 20% RHA by weight of cement at 28 days curing. Strength increase of 4.02% at the age of 28 days was determined to 20% RHA ratio comparing the control mortar results. Over this utilization ratio, a reduction value with 1.72% was recorded according to the turning point. However, even the maximum 25%RHA ratio used in the research, compressive strength of the mortars tested at 28 days of curing was higher value of 2.18% comparing the control mortar strength value. The strength value of 1.5 N/mm² for CS II class was ensured for all RHA utilization ratios at this curing age. The change in strength properties of the test samples in older age was evaluated with analyses at 90 and 120 days of curing in this research work. At these curing ages, compressive strength trend of LCCM samples shows a similarity with the strength trend at 28 days of curing time (Figure 8). The strength increases up to 20% RHA ratios comparing the control mixture sample was determined as the value of 18.85% and 21.69% for 90 and 120 days of curing times, respectively. Over the using ratio of 20% RHA, a reduction in strength was recorded as a value of 3.35% according to the turning point for these two curing ages. However, even the maximum 25% RHA ratio used in the research, compressive strengths of the mortars tested at these two curing ages were higher as the values of 14.75% and 17.67% comparing the control mortar strength value, respectively. The strength value of 1.5 N/mm² for CS II class was ensured for all RHA utilization ratios at both 90 and 120 days of curing age. It can be noted that the strength development for LCCM samples at long term ages was higher while at the early ages are comparable. This is due to having very fine size RHA particles which may have allowed the RHA particles to increase the reaction with Ca(OH)₂ to give more calcium silicate hydrate (C-S-H) resulted in higher compressive and flexural strength as well as stated in [2]. To estimate the relationship between flexural strength and compressive strength values for LCCM tested samples, an empirical model was statistical developed based on all the mechanical strength values. The empirical model is depicted as follows:

\[ \sigma_f = 0.14(\sigma_c)(\sqrt[3]{T}) \]  

Where; \( \sigma_f \) is average flexural strength of samples in N/mm², \( \sigma_c \) is average compressive strength of samples in N/mm² and T is curing time of samples in days. Using this empirical approach, flexural strength of the mortar samples could be estimated on the basis of its compressive strength and curing age.

4. Conclusion

In this paper, a critical review on the influences of RHA on the strength of lightweight cementitious composite mortars is mainly presented. In addition, properties and pozzolanic activity of RHA, advantages and disadvantages of supplementary use of RHA in mortar are mentioned here. As the RHA is an agricultural residue and naturally available, it can lower the construction cost. The result analysed in this work presents, the influence of addition of RHA in the behaviour of mortar is quite satisfactory. The use of RHA significantly improves the mortar strength and can be used as pozzolanic material in cement mortar. However, fine grinding and burning in controlled temperature may be required to get good quality RHA. Based on the experimental results of this study, the following conclusions were drawn: Effective consumption of RHA in mortar has a great importance regarding strength, durability and cost effectiveness of mortar up to a certain replacement percent. It may be concluded that the water demand for same workability of control mix mortar for standard consistency is linearly increased with an increase of cement replacement level by RHA. The addition of RHA to
cement paste at all replacement level causes increase in the initial and final setting time. The use of RHA at 20% replacement level results is good in compression at short and long duration. The used RHA is good for pozzolanic material and replace the OPC at 20% without an effect on the compressive strength at long time. This study indicates that up to 28 days LCCM samples have higher strength than the RHA addition sample and at later age (90 and 120 day) the result is reverse up to 20% replacement level of control mixture by Rice Husk Ash. Durability of mortar is also accepted for 20% replacement level. It is concluded from the result that the mortar incorporating rice husk ash is more durable than control mixture up to 20% replacement level. The use of RHA significantly improves the cement mortar strength at the 20% replacement level at the age of 90 days. Based on the discussions presented in this paper, various advantages of RHA - improved strength, reduced material costs due to cement saving, durability properties, environmental benefits to the disposal of RHA waste - have been observed to use in mortar. Having the more benefits using RHA in mortar, it shows a few following disadvantages: Suitable incinerator/furnace as well as grinding method is required for burning and grinding rice husk in order to obtain good quality ash. Strength of concrete is reduced for larger (beyond 20%) replacement. Unburnt RHA is not suitable for concrete production.

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