# MITIGATION OF ALKALI AGREGGATE REACTION OF CONCRETE INCORPORATION RICE HUSK ASH (RHA)

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**Abstract**

There are several years that concrete has exhibited particular roles as most consuming materials among civil engineers. Through these years, several factors in concrete have been studied. The alkali-silica reaction (ASR) is one of these factors that affect the service life of concrete structures. This phenomenon occurs between the alkaline hydroxides in cement paste and that reactive minerals in the aggregate producing an expansive gel that may cause cracking and displacement in concrete structures.

Currently, pozzolanic materials as satisfactory substitution of cement are used to prevent or minimize these cracks and displacements. Recently, the properties of Rice Husk Ash (RHA) as high-quality artificial pozzolanic materials are important issues that specialists are concerned with, especially in East Asia and North America. It is not widely produced and used due to lack of adequate experiments on this material.

In the first part of this research, X-ray test was used to determine the silica content of the burnt rice husk. Attempt was made to determine the optimum temperature and duration of burning. Consequently, temperature of 650 degrees centigrade and 60 minutes burning time was found best combination.

In the second part, an experimental program was carried out to study the effect of different levels of cement replacement (0%, 7%, 10%, and 15%) by RHA on the expansion of mortar bar and concrete prism. The results indicate that it is possible to reduce the expansions, depending on RHA content used and the test used.

**Keywords**: Alkali-Silica Reaction (ASR), Rice Husk Ash (RHA), Mortar Bar, Concrete Prism, Artificial Pozzolanic Materials.

## 1 INTRODUCTION

The alkali-silica reaction (ASR) that occurs between the alkaline hydroxides in cement paste and reactive minerals in the aggregate produces expansive gels that may cause cracking and displacement in concrete structures. Currently, pozzolanic materials, such as fly-ash and natural pozzolans [1, 2, and3], are used to prevent or minimize the deleterious effect of the ASR. While these pozzolans successfully limit the ASR, laboratory experiments must be carried out to determine the optimum amount of pozzolanic material needed to minimize the ASR expansion. Recently, several researches were carried out on effect of Rice Husk Ash (RHA) to prevent the ASR.

The use of rice husk ash in concrete was patented in the year 1924 [4]. Up to 1978, all the researches were concentrated to utilize ash derived from uncontrolled combustion. Mehta published several papers dealing with rice husk ash utilization during this period. He established that burning rice husk under controlled temperature– time conditions produces ash containing silica in amorphous form [5].

Generally, there are two types of RHA in concrete. The type of RHA suitable for pozzolanic activity is amorphous rather than crystalline. Therefore, substantial research has been carried out to produce amorphous silica. The results show that the quality of RHA depends on temperature and burning time. Apparently, for an incinerator temperature up to 700 °C the silica is in amorphous form and silica crystals grew with time of incineration. The combustion environment also affects specific surface area, so that time, temperature and environment also must be considered in the processing of rice husks to produce ash of maximum reactivity [6, 7].

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Hasparyk [8] and her colleagues have found out as depicted in their paper too that RHA is actually effective in alkali aggregate reaction. In the comparison between RHA and SF they found that RHA in the above mentioned reaction (AAR) exhibits the same qualities as SF. The study proved that the both RHA and SF can reduce expansion due to the AAR, depending on the content used. RHA almost achieves expansions of order of 0.1% at 16 days according to ASTM C 1260. However, with replacement as much as 15% they attained lower percentage of expansions that is with an increase in the amount of replacement of these mentioned pozzolans the expansion of the mortar bars has been reduced.

Described as follows are the results of an experimental program to assess the effectiveness of RHA in reducing the ASR expansion in mortar bars and concrete prism. The experimental program included reactive aggregates and three levels of pozzolanic replacements.

## 2 PRODUCTION & OPTIMIZATION OF RICE HUSK ASH QUALITY

### 2.1 Rice husk ash (RHA) production

The quality of RHA as an admixture for cement and concrete depends on its reactivity. The reactivity of RHA contributes to the strength of RHA-based materials by pozzolanic reactions between the silica and the calcium hydroxide liberated during the cement hydration process. These reactions produce additional amounts of calcium silicate hydrate that makes the microstructure of the RHA concrete denser as compared to that of concrete without RHA. The reactivity of RHA depends on amorphous silica content available and on the porous structure of the ash. On the other hand, the ashes produced by burning rice husks under uncontrolled conditions may contain various amounts of un-burnt carbon. In order to supply typical RHA, a special furnace was designed and constructed in the Amirkabir University of Technology. A schematic view of the furnace is shown in Figure 1.

This furnace was built in pilot size having the ability to control the conditions of combustion. The furnace was designed with a possibility for controlling the temperature and the rate of burning. Therefore, the furnace can be used to produce rice husk ashes with various un-burnt carbon contents. At the beginning of combustion, the firing natural gas is burnt directly in the furnace. During this time, the husks are dried and combustion is started. Then, the gas supply as a fuel is discontinued and combustion procedure is continued automatically.

Moreover, there are two ways for supplying required air for combustion. Primary, the hot air is blown into the main storage of ash through a porous plate. Simultaneously, the air is injected from another blower through pipes of air transfer. The air blowers can directly control the combustion procedure.

Temperatures can be measured by thermocouples at the fire zone, in air inlet and outlet zones. The measured temperature in the fire zone shows temperature of ash, directly. This temperature is checked by an electrical controller. The temperature controller is installed on electric control box and can switch on or off the blowers. No control is required during burning process.

### 2.2 Rice husk ash (RHA) optimization

From literature review it can be concluded that burning rice husks at temperature below 700°C produces rice husk ashes with high pozzolanic activity [9, 10, and 11]. Firstly, ashes used for investigating properties of RHA concrete were produced by burning rice husks in the furnace. The highest temperature in the furnace was maintained below 750°C. This temperature was recorded in the fire zone where the rice hush was burnt. The measured temperatures were 550, 600, 650, 700 and 750°C. Furthermore, time of burning was another variable parameter that was investigated at 30 and 60 minutes. In addition, an ash sample was processed at temperature of 1100°C at 5 minutes.

The temperatures can be varied by regulating the blowing air. Therefore ashes with various contents of un-burnt carbon were obtained.

To identify and quantify the major and minor elements present in the samples of obtained rice husk ash, X-Ray Fluorescence (XRF) analysis was carried out. The results are given in table 1. The chemical compositions of the RHA indicate that the material is mainly composed of $SiO2$. The table implies that the ashes produced in the specially designed furnace at low temperature or during 30 minutes are not appropriate due to high loss on ignition. So, they are not appropriate for RHA concretes. Based on results of table 1, figure 2 can be drawn out. Figure 2-(a) can be used to obtain silicon dioxide content from temperature and time duration of burning ashes and figure 2-(b) shows variation of LOI value vs. temperature and time. Fig. 3 shows a photo of rice husk, high carbon RHA, optimum RHA and RHA with crystalline silica.

Afterward, to determine the crystalline compounds present in the various rice husk ash specimens, X-ray Diffraction (XRD) test was carried out. Fig 4 shows XRD patterns of the ashes. The ash patterns were denoted as RHA-Temp.-Min. respectively. The figure shows that silica in the rice husk initially exists in the amorphous form, but will not remain porous and amorphous, when combusted for a prolonged period at a temperature above 650°C, or during less than a few minutes at 1100°C, under oxidizing conditions. It means that the reactivity of rice husk ash is generally decreased by the increase of burning temperature and the heating duration. Burning rice husks at temperature below 650°C produces amorphous crystals of rice husk ashes. Combination of 650°C temperature and 60 minutes burning time seems to present the optimized solution resulting in non-crystallize RHA and lowest burning time.

## 3 EXPERIMENTAL PROGRAM

### 3.1 Materials

The following materials were used in the preparation of the concrete specimens. The natural Osture dam aggregates were used as reactive aggregates. The reactivity of aggregates is checked by petrography and mortar bars tests. The components of aggregate are given in table 4. Type I Portland cement and homogeneous rice husk ash produced by the special designed furnace at 650°C and 60 minutes burning time were used. Table 2 shows the physical and chemical characteristics of RHA (RHA-650-60) and cement.

### 3.2 Test methods

The mortar bars were cast and tested according to ASTM C 1260 [12]. The samples were immersed in a 1 mol NaOH solute on at 80 C. The length change of the mortars was measured over time, up to 27 days. The following replacement levels were studied: 0, 7, 10 and 15% by mass. Three specimens were cast for each mixture. In addition, standard tests for concrete aggregate due to ASTM C 1293 were carried out [13]. The samples were located in saturated humidity at 38°C. The length change of the prisms was measured over time, up to two years. Also RILEM AAR-4 tests were carried out [14, 15]. Three prism specimens were cast for each mixture for both CPT. The differences between the two CPT methods are time duration and temperatures of tests. The AAR-4 tests are carried out in 60°C for six months. Also, the following replacement levels were studied: 0, 7, 10 and 15% by mass for both CPT.

## 4 TEST RESULTS & DISCUSSION

The results of pozzolanic activity test are shown in table 3. Results demonstrate high pozzolanic activity index of RHA over that of the control in accordance with ASTM C-311/ASTM C-618 test method. On the other hand, produced rice husk ash is a high reactive pozzolanic material, and entirely satisfies other requirements.

Results of the expansive behavior of mortar bars according to ASTM C 1260 made with various amounts of RHA are given in figure 5 and 6. In general, the RHA concrete had higher expansion when compared with the permitted amount of expansion at various ages up to 27 days. However, the mortar bar containing 7% RHA has reduced the expansion around 7% in comparison with the reference mortal bars after 27 days.

The expansion of the concrete prism in accordance with ASTM C 1293 is shown in figure 7. Up to 175 days, mixtures containing 7% and 10% RHA reduced the expansion (the former one by 52% and the latter by 33%) when compared with the reference concrete prisms. However, specimens containing 15% RHA show highest expansion (7%) at about 0.045%. Figure 8 presents the expansion rate of concrete prisms up to 175 days.

Similar to mortar bar tests, concrete prisms tested in accordance with AAR-4 method show that replacement of 7% and 10% RHA has reduced the expansion, the former by 23% and the latter by 29%. However, specimens containing 15% RHA reduced expansion at 6 months about 14% but this expansion is about 0.03%. (See figure 9-10).

The trend of the results of both CPT is towards the higher expansion although there is dispersion with time. This is probably due to the measurement error occurred at laboratory condition variations.

## 5 CONCLUSIONS

Based on the results of the present experiments, the following conclusions can be drawn out:

1) The quality of the RHA cement is widely varied due to the differences in the methods of production. So, it is generally advocated to use special incinerators, which can guarantee controlled burning conditions. With the proper production method, rice husk ash of a pozzolanic reactivity

comparable to other pozzolans can be obtained. A special furnace which was designed and constructed was able to produce RHA with various qualities.

2) The burning time and temperature of furnace are important parameters, influencing the reactivity of RHA pozzolans. Investigation on the influence of combustion conditions on the amorphous silica suggests that the RHA produced at 650°C and 60 minutes burning time can be the optimum time-temperature conditions.

3) The results show that the replacement of RHA to control alkali aggregate reaction has an optimum amount which seems to be between 7% and 10 %. This indicates that increasing the amount of RHA, causes an increase in the expansion.

4) Since total RHA alkali equivalent content (1.11%) and also RHA soluble alkali (0.78%) are both higher than cement alkali equivalent content (0.75%), the increase of RHA would lead to the alkali increase of the entire system which was about 0.05% in specimens containing15% RHA.

5) It can be seems that higher replacement level of RHA has resulted in higher expansion. The amount of potassium hydroxide in RHA is high and part of it will be released into the solution. The amount of alkali released at 15 percent RHA replacement seems to be high and increase the Alkalinity of the solution and hence higher expansion occurred. The pessimum value for RHA in controlling the AAR is related to the alkali content of RHA.

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TABLE 1: Results of XRF on rice husk ash samples and cement.

| | | | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $CaO$ | $SO_3$ | $MgO$ | $Na_2O$ | $K_2O$ | $P_2O_5$ | $TiO_2$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| temperature and time duration | 550 | 60min | 75.22 | 0.05 | 0.14 | 0.57 | 0.37 | 0.36 | 0.07 | 1.47 | 0.51 | 0.01 | 21.01 |
| | | 90min | 80.76 | 0.03 | 0.09 | 0.66 | 0.23 | 0.43 | 0.05 | 1.72 | 0.79 | 0.01 | 14.95 |
| | 600 | 60min | 80.55 | 0.02 | 0.24 | 0.59 | 0.34 | 0.39 | 0.06 | 1.65 | 0.44 | 0.02 | 15.33 |
| | | 90min | 85.60 | 0.06 | 0.15 | 0.87 | 0.22 | 0.41 | 0.06 | 1.53 | 0.48 | 0.02 | 9.81 |
| | 650 | 30min | 76.21 | 0.08 | 0.22 | 0.86 | 0.21 | 0.31 | 0.08 | 1.69 | 0.52 | 0.01 | 19.53 |
| | | 60min | 89.61 | 0.04 | 0.22 | 0.91 | 0.15 | 0.42 | 0.07 | 1.58 | 0.41 | 0.02 | 5.91 |
| | | 90min | 90.21 | 0.06 | 0.27 | 0.85 | 0.25 | 0.49 | 0.08 | 1.51 | 0.56 | 0.02 | 5.48 |
| | 700 | 30min | 81.35 | 0.09 | 0.15 | 0.77 | 0.18 | 0.33 | 0.08 | 1.72 | 0.53 | 0.02 | 14.53 |
| | | 60min | 89.93 | 0.06 | 0.11 | 0.88 | 0.14 | 0.39 | 0.09 | 1.48 | 0.55 | 0.02 | 6.01 |
| | | 90min | 92.19 | 0.09 | 0.10 | 0.71 | 0.09 | 0.41 | 0.05 | 1.64 | 0.41 | 0.01 | 4.14 |
| | 750 | 30min | 84.22 | 0.09 | 0.18 | 0.54 | 0.17 | 0.38 | 0.06 | 1.35 | 0.61 | 0.02 | 12.09 |
| | | 60min | 93.11 | 0.08 | 0.27 | 0.67 | 0.11 | 0.44 | 0.06 | 1.69 | 0.63 | 0.02 | 2.67 |
| | 1100 | 5min | 95.31 | 0.04 | 0.11 | 0.78 | 0.11 | 0.41 | 0.09 | 1.61 | 0.45 | 0.01 | 0.84 |
| Cement type I | | | 21.50 | 3.68 | 2.76 | 61.5 | 2.5 | 4.8 | 0.12 | 0.95 | 0.23 | 0.04 | 1.35 |

TABLE 2: Physical and chemical characteristics of cement and RHA.

| | *Physical Tests* | | *Chemical Analyses, %* | | | | | | | | *Bogue Composition, %* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Specific Gravity($g/cm^3$) | Blaine, ($cm^2/g$) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | LOI | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ |
| *RHA* | 2.15 | 3600 | 89.61 | 0.04 | 0.22 | 0.91 | 0.42 | 0.07 | 1.58 | 5.91 | — | — | — | — |
| *Cement* | 3.21 | 3200 | 21.50 | 3.68 | 2.76 | 61.50 | 4.80 | 0.12 | 0.95 | 1.35 | 51.1 | 23.1 | 5.1 | 8.4 |

TABLE 3: Comparison in chemical and physical specifications of produced RHA with ASTM C618-03.

| ***Chemical Requirements*** | *ASTM C618-03* | *RHA results* |
|---|---|---|
| $SiO_2 + Al_2O_3 + Fe_2O_3$, min., % | 70 | 89.9 |
| $SO_3$, max., % | 4 | 0.15 |
| Moisture Content, max., % | 3 | 0.23 |
| Loss On Ignition (LOI), max., % | 6 | 5.9 |
| ***Physical Requirements*** | *ASTM C618-03* | *RHA results* |
| Fineness: Amount retained when wet-sieved on 45 μm sieve, max, % | 34 | 8 |
| Strength Activity Index (20% RHA) at 3-day, min. % control | --- | 102 |
| Strength Activity Index (20% RHA) at 7-day, min. % control | 75 | 106 |
| Strength Activity Index (20% RHA) at 28-day, min. % control | 75 | 110 |

TABLE 4: The results of petrography test (ASTM C295).

| | *Calcite and dolomite* | *Granite, gneiss, feldspars and quartz* | *Chert, rhyolite and phylite* | *Igneous* | *Marl* | *Detrital* |
|---|---|---|---|---|---|---|
| *Fine aggregate* | 6.6% | 22.7% | 34% | 29.1% | 7.6% | 0.0% |
| *Coarse aggregate* | 8.6% | 16.3% | 25.2% | 25.5% | 8.1% | 16.3% |

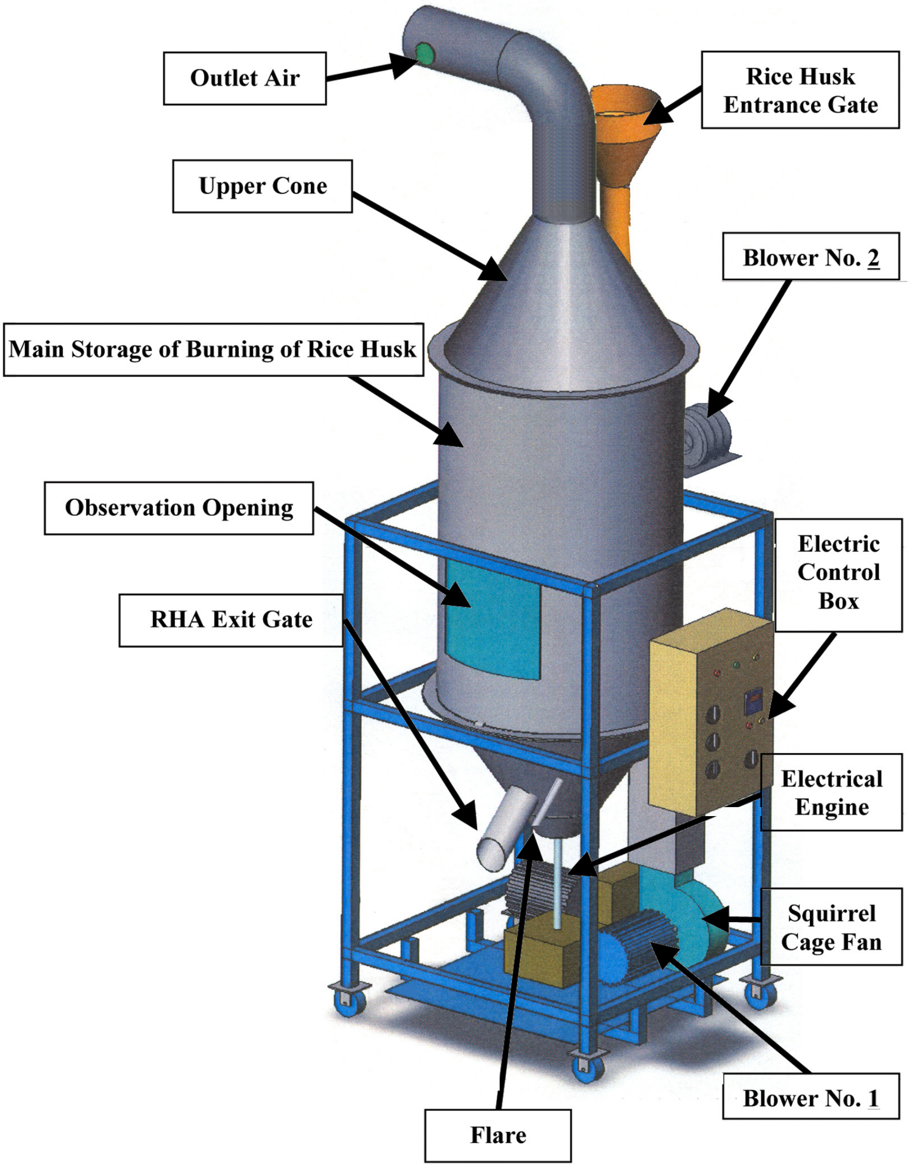


Figure 1: schematic shape of rice husk ash furnace.

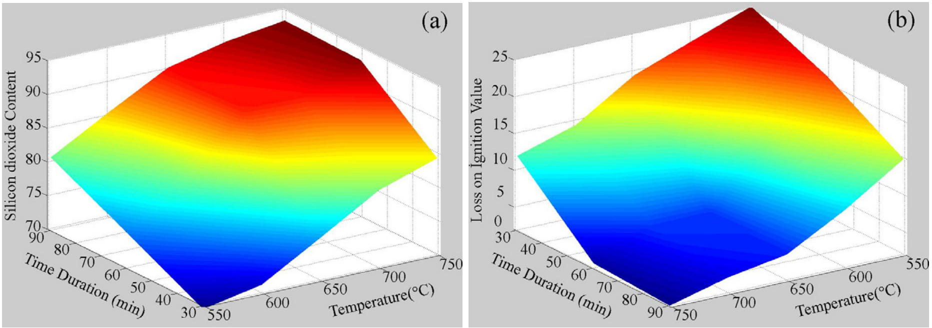


Figure 2: Estimated variation of (a) $SiO_2$ and (b) LOI VS. temperature and time duration.

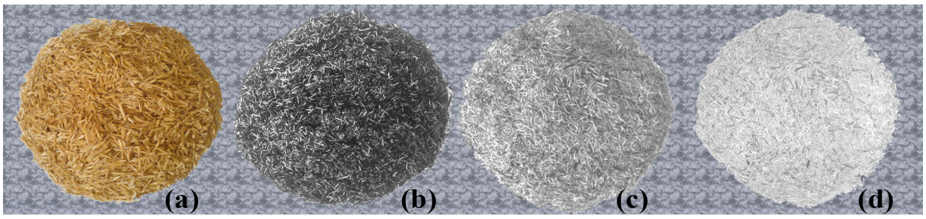


Figure 3: (a) rice husk (b) high carbon RHA (c) optimum RHA (d) RHA with crystalline silica.

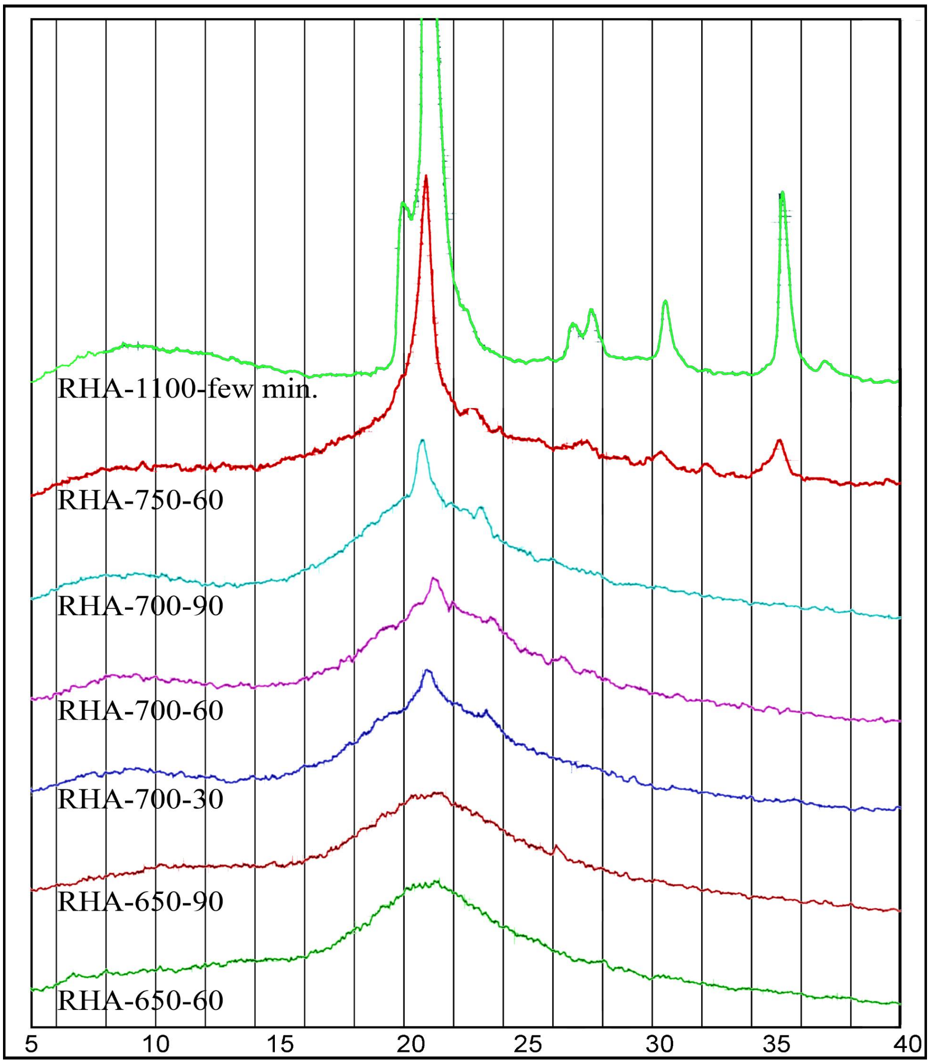


Figure 4: Results of XRD on rice husk ash samples and cement.

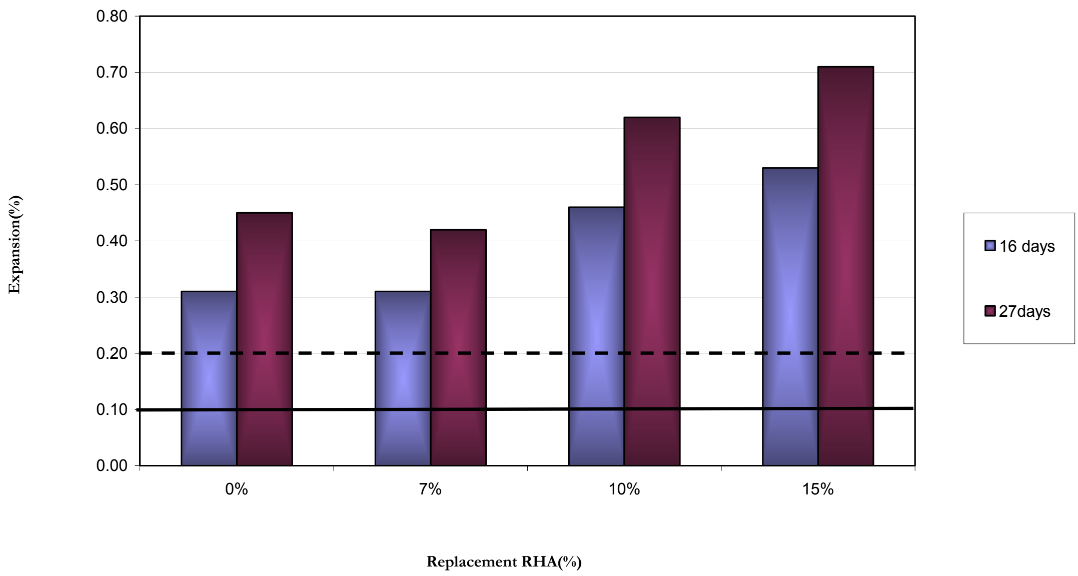


Fig 5: Expansion of mortar bars at 16 and 27 days.

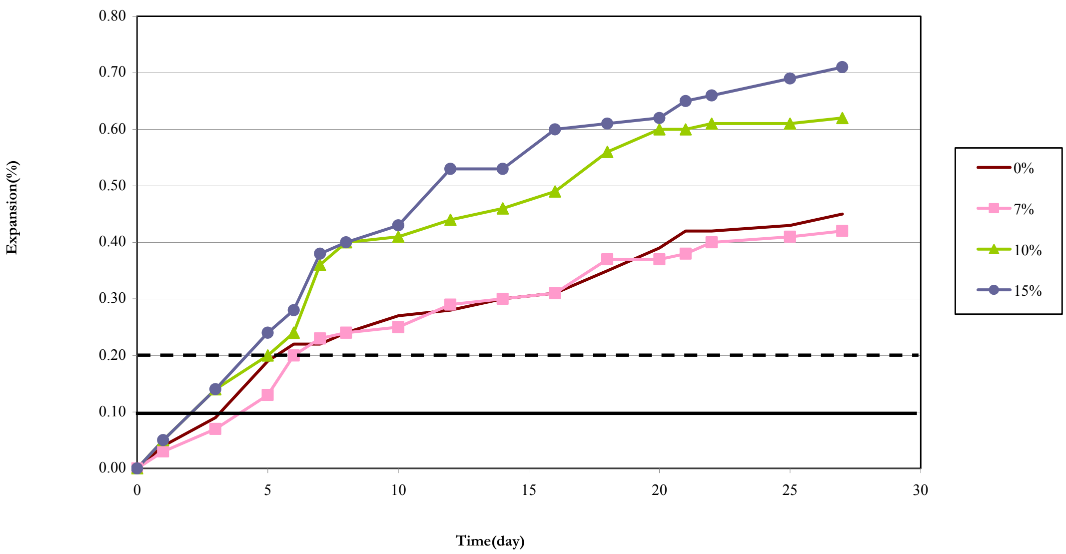


Fig 6: Effect of RHA content on expansion of mortar bars (ASTM C 1260).

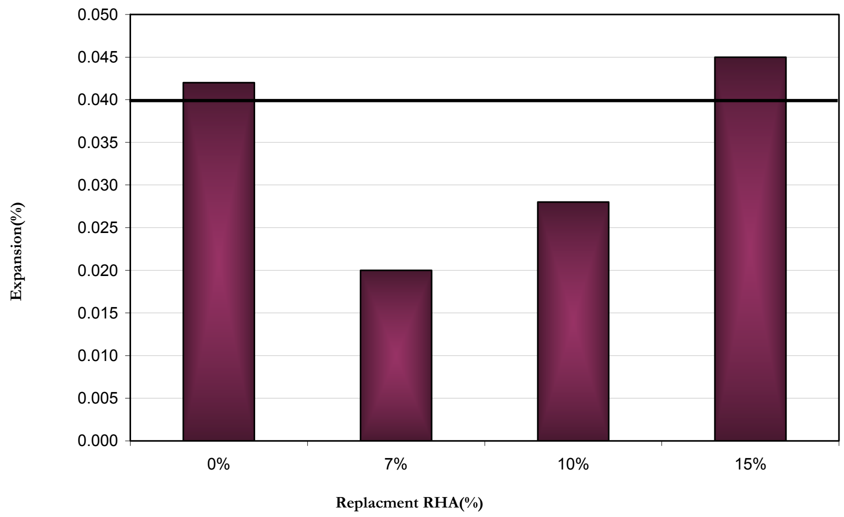


Fig 7: Expansion of concrete prisms (ASTM C 1293) at 175 days.

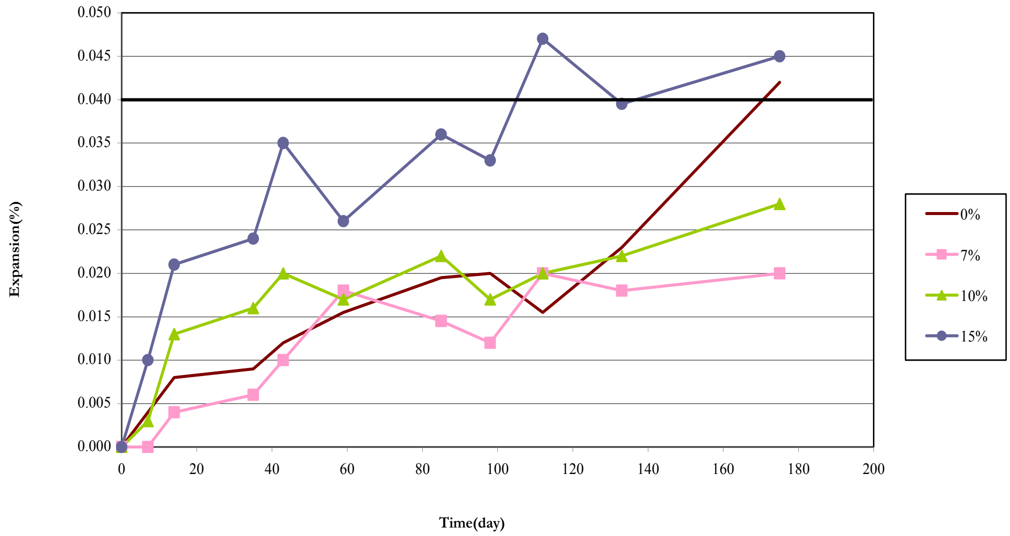


Fig 8: Effect of RHA content on expansion of concrete prism (ASTM C 1293).

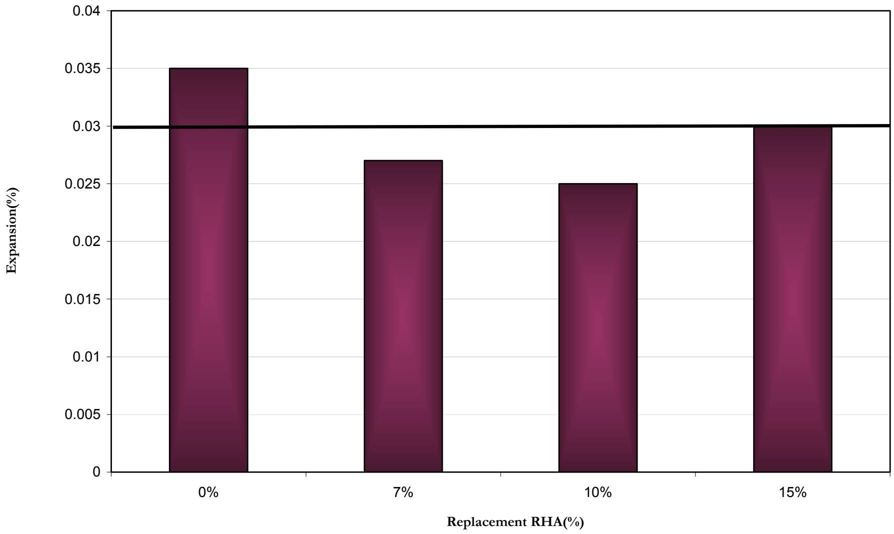


Fig 9: Expansion of concrete prisms (RILEM AAR-4) at 6 months.

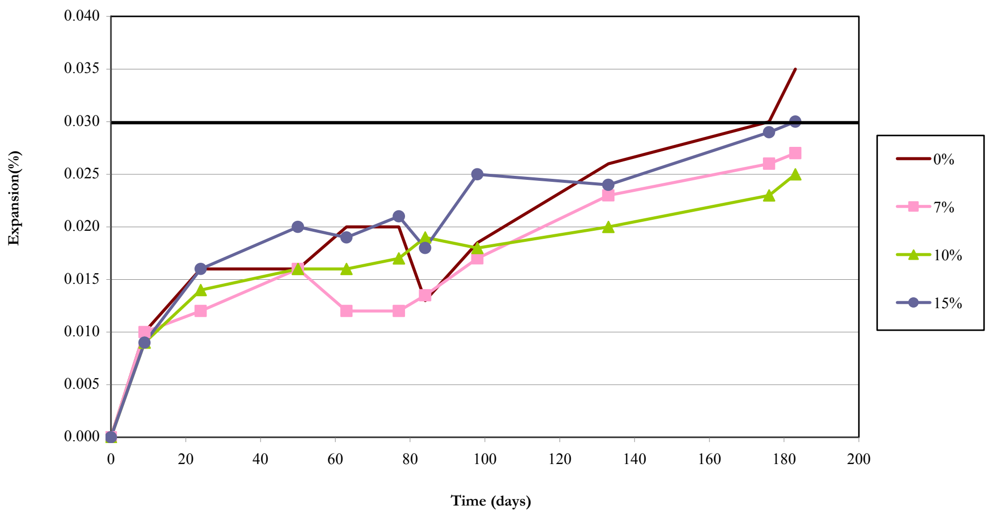


Fig 10: Effect of RHA content on expansion of concrete prism (RILEM AAR-4).