Mechanical properties and shrinkage and expansion assessment of rice husk ash concrete and its Comparison with the Control Concrete

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Abstract— the possibility of using of rice husk ash (RHA) of Guilan (a province located in the north of Iran) (RHA) in concrete was studied by performing experiments. Mechanical properties and shrinkage and expansion of concrete containing different percentage of RHA and the control concrete consisting of cement type II were investigated. For studying, a number of cube and prism concrete specimens containing of 5 to 30% of RHA with constant water to binder ratio of 0.4 were casted and the compressive strength, tensile strength, shrinkage and expansion for water curing conditions up to 360 days were measured.

The tests results show that the cement replacement of rice husk ash (RHA) caused both the quality and mechanical properties alterations. It is shown that the compressive strength, tensile strength increase also shrinkage and expansion of specimens were increased that should be controlled in mass concrete structures.

Keywords— Rice Husk Ash, Mechanical Properties, Shrinkage and Expansion, Pozzolan.

1- INTRODUCTION

A large number of researches have been directed towards the utilization of waste materials [1, 2]. For the construction industry, the development and use of blended cements is growing rapidly. Pozzolans from industrial and agricultural by-products such as fly ash and rice husk ash are receiving more attention now since their uses generally improve the properties of the blended cement concrete, the cost and the reduction of negative environmental effects. A plenty of natural pozzolans can be found in the world, and in Iran also there are very reach sources of pozzolans.

Rice husks, are one of the major agricultural by-products which are the shells produced during the dehusking operation of paddy rice. It constitutes 20% of the 500 million tons of paddy produced in the world [3]. In the north of Iran tons of it is burnt at the end of summer every year and local people call it waste of rice farms (Fig. 1).

When rice husk is burnt, about 20% by weight of the husk is recovered as ash in which more than 75% by weight is silica. It is worth mentioning that the use of RHA in concrete may lead to improve the properties of fresh concrete, the reduced heat evolution, the reduced permeability, and the increased strength at longer ages [4,5].

The use of Rice Husk Ash (RHA) in concrete was patented in the year 1924 [6]. Initially rice husk was converted into ash by open heap village burning method at a temperature, ranging from 300°C to 450 °C [7]. When the husk was converted to ash by uncontrolled burning below 500°C, the ignition was not completed and considerable amount of carbon that was not burnt is found in the resulting ash [8]. Carbon content in excess of 30% was expected to have an adverse effect upon the pozzolanic activity of RHA [9]. The ash produced by controlled burning of the rice husk between 550°C and 700 °C incinerating temperature for 1 h transforms the silica content of the ash into non-crystalline or amorphous silica. The silica content in rice husk ash is high at approximately 90%. Silica in amorphous form is suitable for use as a pozzolan.

Fig 1- Guilan rice farms

Fig 2- Guilan province on the north of Caspian sea in Iran (from Google earth)
Research and development in various parts of the world was led to the conclusion that RHA is suitable for partial replacement because of its very high silica content [1, 2]. The reactivity of RHA is attributed to its high content of amorphous silica, and to its very large surface area governed by the porous structure of the particles [10, 11]. Generally, reactivity is also favored by increasing fineness of the pozzolanic material [12, 13]. However, Mehta [14] has reported that grinding of RHA to a high degree of fineness should be avoided, since it derives its pozzolanic activity mainly from the internal surface area of the particles. By blending rice husk ash with course cement, higher packing can be expected, leading to improved behavior of blended systems [15]. The amount of replacement for cement is influenced by the nature of the silica, fineness of the ash and the presence of other materials such as carbon. Guilan is a province in the north of Iran that most rice farms of Iran are in it (Fig. 2). To find out the proper percentage of the Guilan RHA, replacement with cements type II a number of tests on concrete specimens containing of 5, 10, 12 15, and 30% of RHA with a constant water to cement ratio of 0.4 were carried out to measure and compare the compressive and tensile strength, shrinkage, expansion at different ages and curing conditions for concrete specimens of zero and optimum RHA percentage.

2. Experimental Programme

2.1- Materials and initial tests

The RHA was obtained by burning at relatively high temperatures (450-550°C) which led to the crystallization of the amorphous silica [16]. To be used as a pozzolanic material, the ash was ground by means of a laboratory 2ball mill until certain fineness (Fig. 3&4).

The rice husk ash passing through sieve No. 325 (sieve opening 45 mm) was considered for the partial replacement of cement. Figure 5 shows micrograph of Guilan RHA by SEM scanning. As concluded from this figure, grains are mostly angular edged grains with different particle sizes.

The rice husk ash, provided from burning of husk of Guilan rice, had a high content of SiO2, Al2O3 and Fe2O3 (91.98% (Table 1)) by weight. To find the pozzolanic activity index of the RHA, compressive strength method and Thermo-Gravimetric analysis (TGA) was performed for cement type II and the results are shown in Tables 2 and 3.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>CaO</th>
<th>MgO</th>
<th>SO3</th>
<th>K2O</th>
<th>Na2O</th>
<th>C3A</th>
<th>C4AF</th>
<th>L.S.F.</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>21.75</td>
<td>4.90</td>
<td>3.92</td>
<td>2.72</td>
<td>1.8</td>
<td>2.15</td>
<td>0.50</td>
<td>0.38</td>
<td>6.40</td>
<td>11.90</td>
<td>90.6</td>
<td>-</td>
</tr>
<tr>
<td>RHA</td>
<td>79.34</td>
<td>8.31</td>
<td>4.24</td>
<td>1.72</td>
<td>0.98</td>
<td>0.03</td>
<td>1.23</td>
<td>1.12</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.32</td>
</tr>
<tr>
<td>SAN</td>
<td>63.80</td>
<td>13.00</td>
<td>5.70</td>
<td>4.0</td>
<td>2.0</td>
<td>-</td>
<td>2.50</td>
<td>3.80</td>
<td>24.8</td>
<td>17.3</td>
<td>2.02</td>
<td>4.8</td>
</tr>
</tbody>
</table>

The chemical composition and physical properties of cements of cement type II and RHA as a binder material are given in Table 1. In this Table, the specification of Santorum earth [17] is presented for comparison. As it is indicated, the Portland cements complied with ASTM C311-98b) [18].

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Symbols</th>
<th>Compressive strength (kg/cm²)</th>
<th>Pozzolanic strength activity index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>28</td>
</tr>
<tr>
<td>Cement type II</td>
<td>II</td>
<td>306</td>
<td>379</td>
</tr>
<tr>
<td>RHA</td>
<td>RHA</td>
<td>261</td>
<td>359</td>
</tr>
</tbody>
</table>

Fig. 3- Furnace for burning rice husks
Fig. 4- laboratory ball mill
Fig. 5- SEM micrograph of the Guilan RHA

Table 1 - Chemical composition of cements type II, Guilan RHA and Santorum earth

Table 2 - Result of Pozzolanic activity index and compressive strength test
2.2 Mix designs and used aggregates
Based on the evaluation and the maximum of 30% RHA cement replacement in Iran, it was decided to testify the range of 5%, 10%, 12%, 15% & 30% of pozzolan to find out their mechanical properties. Also, from the Thermo-Gravimetric results, the pozzolanic activities at low ages were not considerable and for a more confidential judgment of RHA behavior, it was decided to up to at least 90 days.

By using ACI 211 [19] method and from author previous experience, the following mixed design (Table 4) was selected as constant control specimens and other RHA specimens were casted using the above mentioned percentages of RHA as cement replacement. The Blain and remainder on sieve No. 170 of used cements are shown in Table 5.

2.3 Casting and curing
Cube and prism samples were cast in accordance to standard method. After casting, samples were covered with two layers of plastic sheets and placed in temperature controlled room at 20±1 ºC for 24 hours. All samples after 24 hours divided into two different cured conditions; 1 day curing in ordinary water then curing in air (curing condition “Dry”) and in water (curing condition “Wet”). Based on the trial results of Table 2&3, further investigation including compressive and flexural strength, shrinkage and swelling were performed.

2.4. Compressive strength
Compressive strength of specimen mixes was measured on cubes of 100 mm at 3, 7, 14, 28, 90, 180 and 365 days age and the strength development of mixes based on average strength of three samples tested at each age are shown in Figure 8. Comparing the compressive strength of the control and RHA concrete specimens, it is obvious that, it can be seen that, almost for all cases at all ages the compressive strength of the RHA specimens cured in ordinary water with an average temperature of 20±1 ºC at the first ages were less than control specimens Meanwhile, for the ages between 28 to 365 days, the compressive strength of specimens made of RHA obtaining strength increasing of higher values respectively.

From figure 8, it can be seen that, the increase in compressive strength of specimens containing of RHA specimens is relatively uniform and more rapid than the control specimens. It is noted that such a behavior that shows the rate of strength for RHA is advantageous for mass concrete, where a large volumes of concrete are placed (e.g. gravity dams) and the danger of thermal cracking is considerable.

2.5. Flexural strength
A total number of prism samples (prism specimens of 100* 100* 450 mm, based on ASTM C78-94 [21]) were tested at 28, 90, 180 and 365 days (Figure 9) and average results of three samples are reported.

Figures 8 and 9 show the results of flexural strength of samples with and without RHA stored in water. From this figure it was found that the gain in flexural strength is reduced with the passage of time and normally for the specimens containing of

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### Table 3- Results of Thermo-Gravimetric test

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Pozzolanic activity</th>
<th>Loss on ignition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 day</td>
<td>3 days</td>
</tr>
<tr>
<td>RHA</td>
<td>24.14</td>
<td>35.39</td>
</tr>
</tbody>
</table>
RHA, the intention in increasing the flexural strength is more than that of the control specimens.

Fig. 8- Flexural specimens curing and flexural test

2.6. Shrinkage
Shrinkage in concrete is caused by loss of water by evaporation or by hydration of cement, and also by carbonation. There are different types of shrinkage, however here, the drying shrinkage is measured and reported. It should be mentioned that the drying shrinkage of concrete are affected by several factors such as relative humidity, type of aggregate, W/C ratio, modulus of elasticity of aggregate etc. Results of average shrinkage of two prism samples (100*100*450 mm) made with different concrete mixes at different ages are shown in Figure 10. The samples are kept at air temperature of 21 to 27º C with a relative humidity (R.H.) of 75%.

Results of average shrinkage of two prism samples (100*100*450 mm) made with different concrete mixes at different ages are shown in Figure 10. The samples are kept at air temperature of 21 to 27º C with a relative humidity (R.H.) of 75%.

It can be seen that the amounts of shrinkage for the RHA specimens are more than that of the control specimens. The highest rate of shrinkage is for the first 7 days and after that the growing up rate of shrinkage decreases. Lots of different factors affect the drying shrinkage. In this study apart from the percentage of RHA replacement, all other factors are same and therefore they can't be used for the amount of shrinkage judgment. It seems because RHA pozzolanic activity increase the small holes (capillary pores) in hydration products and also shrinkage in concrete depends on water imprisoned in small holes in concrete, therefore, pozzolanic concretes has more shrinkage than non pozzolanic concretes in the same curing conditions.

Fig. 10 Shrinkage value (μ m/m) versus time with/without RHA (cement type II)

2.7. Swelling (Expansion)
The same prism samples (100*100*450 mm) as shrinkage test were cast after 24 hours, the specimens were kept either in ordinary water (W) for one year. The swelling of samples made with different mixes was measured using signed points and mechanical strain gauges at different ages (Figure 11). Results of average swelling of two samples for cement type II are shown in Figure 12. The samples are kept at air temperature of 21 to 27º C.

With respect to Figure 12 it can be obtained that for both the exposure conditions, the amounts of RHA specimen and by increasing the percentage of RHA, the amount of expansion is considerably increased.

Fig 11- shrinkage and expansion testing

Fig. 9- Concrete Flexural strength of different mixes consisting cement type II cured in (W)
due to swelling for different types of
µm/m

Fig. 12 Swelling value (µ m/m) versus time for mixes with/without RHA (cured in (W), cement type II)

The first result shows that by attracting available water in the RHA mix concretes expansion will happen. A part of this expansion could also be due to the chemical factors such as the percentage of C3A, C4AF & etc. The above results prove the availability of minerals expansion, as generally the pozzolanic reactions are completed at latter ages, whereas water attraction by minerals expansion are occurred at the earlier ages.

3. Microstructure of mortar phase with/without RHA

The reaction of the RHA present of water and $Ca(OH)_2$ formed during the hydration of cement that caused the formation of calcium silicate hydrate $C - S - H$ which is responsible for the strength in cement-based materials. To verify this mechanism, the mortar specimens containing Guilan RHA, which had 360 days of water curing, were examined by scanning electron microscopy (SEM). The microstructure of the mortar mixture containing RHA revealed that the formation of hydration products which lapped and jointed together was denser and more compact (Figure 13). By SEM study of specimens it is clear that the microstructure of the mortar mixture containing RP together was denser and more compact than control specimen. It maybe will be because of RHA pozzolanic activity that fills small pores between aggregates and cement gel (Figure 14).

4. Conclusions

By using Guilan RHA as a cement replacement the following conclusion can be drawn:
1- The heat of hydration reduces because of cement decreasing. This is advantage especially for mass concrete and also concreting in a hot whether will be more reliable.
2- Compressive strength of specimens in longer ages will be more than that of the control concrete.
3- The tensile strength even at earlier age will be more than that of the control concrete.
Fig. 14 - Pozzolanic activity of RHA in cement mortars

4- The amounts expansions are more than that of the control specimens and by increasing the percentage of RHA, the amount of expansion is considerably increased.

5- Amounts of shrinkage for the RHA specimens are more than that of the control specimens. The highest rate of shrinkage is for the first 7 days and after that the growing up rate of shrinkage decreases

8- By SEM study of specimens it is clear that the microstructure of the mortar mixture containing Guilan RHA together was denser and more compact than control specimen.

REFERENCE


[18] ASTM C311- 98b. “Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland - Cement Concrete”.

