Effect of rice husk ash on hydrotechnical concrete behavior

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Abstract. Vietnam is one of the leading rice exporters in the world. Popularly, as other rice producing countries, rice husks from rice processing in this nation are used widely not only in electricity generation and silicon making but also one kind of raw material for various building materials production. This article presents a reusing waste method of Rice Husk Ash (RHA) in Vietnam to improve the behavior of hydrotechnical concrete (HTC), one of the most significant building materials.

In this study, RHA plays a role as a highly active fine mineral additives, containing 88.42% amorphous SiO₂ oxide in component. The combination of RHA and superplastizier ACE 388 as mineral additives is able to modify the concrete structure. Not only the compressive strength of hydrotechnical concrete at the age of 28 days increase 7.39% (from 11.71 to 19.1%), but also its water resistance rises up to 50% (from the point of 25%) due to compaction of the structure.

The experimental results of permeability of chloride-ion according to standard ASTM C1202-97 (American) show that the HTC patterns containing 10% and 20% RHA by mass of the binder have the average value of electrical energy, respectively 351.18 C and 297 C. While other control samples without RHA have the average value of electrical energy of 1013.22 C. In comparison to the American Concrete Association classification table, these chlorine-ion permeability values of samples HTC-10 and HTC-20 are, precisely, at low level. Therefore, hydraulic concrete, using modified structure from mineral additives of superplastizer ACE 388 and RHA, is appropriate building material for construction of irrigation works and hydroelectric projects in Vietnam.

Key words: rice husk and straw, rice husk ash, amorphous SiO₂ oxide, hydraulic structure, hydrotechnical concrete, compressive strength, water resistance, impermeability to chloride-ion.

1. Introduction

Vietnam, located in tropical climate area, has strong differentiation of seasons. This country stretches lengthen from the North to the South, with a coastline of 3260 km long. Recently, the number of hydraulic projects in the coastal zone and the delta has increased several times. The main addition to a rapid growth in hydraulic structures are reservoir systems, canals and water pipelines throughout the country [1]. Based on some research analysis results, more than 50% of the nodes and structures of the hydraulic structures in Vietnam were completely damaged or destroyed after 5 ÷ 20 years operation [1, 2].

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The hydrotechnical concrete is designed to fabricate structure or construct permanent or temporary works in hydraulic environment such as hydroelectric, irrigation works, industrial hydro projects, drainage projects... [3].

Depending on the placement of concrete in construction work, the concrete structure is categorized into three areas including the underwater, above water, the water level up and down. It is said in some documents [4] that concrete of underground hydraulic projects is considered as concrete underwater which requires special water and erosion resistance.

Under the influence of groundwater in the long-term operation, the strength and durability of concrete, reinforced concrete structure are reduced. In detail, cracks appear in the concrete, the protective layer and exposure of steel reinforcements gradually erodes leading to the corrosion by salt ions and acid through this concrete layer [5]. Therefore, one of the most important solution to advance the durability and longevity of hydraulic structures is that increase the density of the microstructure of concrete for impermeability improvement.

Moreover, Vietnam is known as one of the most rice exporters in the world caused of great amount of agricultural waste as rice husk and straw. The research paper [6] shows that milling of 1 ton of paddy will discharge 200 kg rice husk which evacuates 40 kg of ash after burning. According to the Food and Agriculture Organization (FAO) [7], the production of paddy in the world in 2003 was 588.56 million tons. In which, Vietnam was accounted for 34.51 million tons. By simple calculations, the amount of ash that can be obtained by burning the amount of rice husk in 2003 in the world and especially in Vietnam will be 23.54 million tons and 1.38 million tons respectively. Thus, recycling rice husk and straw not only makes use of natural waste but also more importantly reduce negative impact on the environment.

In the rice producing countries, agricultural wastes (rice husks and straw) which are familiar terms, are used widely in electricity generation [8] and silicon making [9] activities. They also play a role as one kind of raw material for various building materials production, including fine mineral admixtures in concrete mixtures and mortars. Since 1994, there were different researches on the field of rice husk ash in Vietnam (one of rice exporters) as well as in other countries in the world as building materials. Table 1 shows the summary of these research until 2018.

Table 1. Literature review of the use of RHA as a raw material for building material production

| Year | Authors | Research Title | Types of building materials |
|------|---------|----------------|----------------------------|
| 1994 | P.K. Mehta et al. | Rice Husk Ash-a Unique Supplementary Cementing Material, in: Advances in Concrete Technology [10] | Cement |
| 2006 | Bui Danh Dai | Effects of active Rice Husk Ash on the properties of concrete mixtures and mortar [11] | Concrete mixtures and mortar |
| 2010 | A.N. Givi et al. | Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete [12] | Binary blended concrete |
| 2012 | Nguyen Dinh Chinh et al. | High-strength concretes with integrated use of rice husk ash, fly ash and superplasticizers[13] Research on effect of rice husk ash and superplasticizer on the properties of mortar and concrete [14] | High-strength concretes Mortar and concrete |
| 2013 | Ngo Van Toan et al. | Effect of rice husk ash and fly ash on the compressive strength of high performance concrete [15] | High performance concrete |

It can be seen that almost researches concentrate on the effect of rice husk ash on concrete and mortar properties. While this paper will do a research on the effect of organic-mineral modifier, consisting of RHA in combination with the superplasticizer ACE 388 “Sure Tec” BASF (Germany),

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on the water permeability, chloride-ion permeability and the compressive strength of concrete at the age of 3, 7, 14 and 28 days.

2. Methods
On the one hand, this paper will analyze the chemical composition and the grain composition of RHA by laser granulometry method. On the other hand, method of calculation preliminary compositions of concrete mixture is applied in accordance with standard ACI 211.4R-93, in combination with absolute volume method. The flow ability of concrete mixture is determined by the slump flow of Abrams’ cone with dimensions of 100x200x300 mm [16]. The compressive strength of concrete is determined by a 100x100x100 mm cube pattern by Russian standard GOST 10180-2012 at the ages of 3, 7, 14 and 28 days. The waterproof of concrete is specified by Russian standard of GOST 12730.5-84. Besides, evaluating of chloride-ion permeability of concrete is based on ASTM C1202-97 (American).

3. Materials
The following materials have been used in hydrotechnical concrete for construction of hydraulic works:
- Portland Cement (PC) type CEM II 42.5 N manufactured at “But Son” factory (Viet Nam), specific gravity of 3.15 g/cm³, specific surface area of 362 cm²/g. The results of chemical analysis and mineralogical composition of cement are presented in Table 2 and 3.  
  
  **Table 2. Chemical composition of cement “But Son”**

| Oxide composition (%) | CaO | SiO₂ | Al₂O₃ | Fe₂O₃ | MgO | SO₃ | LOI |
|-----------------------|-----|------|-------|-------|-----|-----|-----|
|                       | 61.35 | 25.5 | 4.42 | 4.04 | 2.17 | 1.45 | 1.07 |

Loss on ignition.

**Table 3. Mineralogical Composition of cement “But Son”**

| Mineral composition (%) | C₃S | C₂S | C₃A | C₄AF | Other |
|-------------------------|-----|-----|-----|------|-------|
|                         | 52.3 | 27.7 | 5.2 | 11.4 | 3.4 |

- Quartz sand (QS) originally from the golden sand of “Lo River” (Viet Nam), Mₖ = 2.92, specific weight of 2.62 g/cm³ and the volume of compacted state is 1620 kg/m³.
- Crushed limestone (CL) produced from the quarry “Kien Khe” (Viet Nam) with the size of 5 - 10 mm and 10 - 20 mm, specific weight of 2.65 g/cm³ and volume of the compacted state is 1600 kg/m³.
- Water (W) for mixing concrete is purified water satisfied by GOST 23732-2011.
- Superplasticizers ACE 388 (A388) “Sure Tec” BASF (Germany). It is a new generation chemical additives based on polycarboxylate with density of 1.1 g/cm³ at 20 ± 5°C.
- Rice husk ash (RHA) of Vietnam with specific weight of 2.15 g/cm³, the volume of natural porous state is 572 kg/m³ and the water needs is 100.7%. The chemical composition of the RHA is shown in Table 4.

**Table 4. Chemical composition of RHA**

| Average chemical composition (%) | SiO₂ | Al₂O₃ | Fe₂O₃ | SO₃ | K₂O | Na₂O | MgO | CaO | P₂O₅ | LOI |
|----------------------------------|------|-------|-------|-----|-----|------|-----|-----|------|-----|
|                                  | 89.22 | 1.2   | 0.35  | 0.5 | 1.14 | 0.75 | 0.8 | 1.34 | 0.15 | 4.55 |

The RHA grain composition, is determined by Laser method, is shown in Fig. 1.
Figure 1. The grain composition of RHA

The rice husks are collected from Rice processing Plants in the North of Vietnam. They are dried naturally, and then burned in the rice husk furnace of the laboratory at temperature 800°C. After that, the rice husk is stabilized and cooled in one day to the temperature of environment. Next, the husk ash was grounded by a ball mill in 1 hour in order to obtain RHA in the form of fine powder (Fig. 2).

Figure 2. Technological scheme for obtaining RHA from rice husks

4. Results and discussion

When designing the composition of concrete mixtures for high performance hydraulic constructs based on the following provisions:

- The content RHA is ranging from 0% (control sample) to 20% by mass of PC [11].
- Based on research [14, 15], the ratio of water on Portland cement is chosen as \( \frac{W}{PC} = 0.32 \).
- According to [17], mass Portland cement is fixed as \( PC = 550 \text{ kg/m}^3 \).
- According to the result [18], the content of macadam by grade 5 ÷ 10 mm and 10 ÷ 20 mm are 35.5% and 64.5% by mass of coarse aggregate.
- The volume of crushed limestone \( V_{CL} \) at compacted state in 1 m³ of concrete mix with \( D_{max} = 20 \text{ mm} \) and the modulus of sand \( M_k = 2.92 \) is \( V_{CL} = 0.72 \), according to ACI 211.4R-93 [19].
- The calculation of quartz sand content in 1 m³ of concrete of the control sample is done by absolute volume method [20].
- The superplasticizer ACE 388 is equally to 1.0% by mass of PC [21].
- The volume of air contained in 1 m³ of concrete mixture is 1.5%. 


On the basis of the above data, the preliminary of the material compositions in the dry state of the concrete mixture is shown in Table 5.

**Table 5.** Preliminary compositions of concrete mixtures

| Types of sample | RHA (%) | W<sup>b</sup> | Compositions of concrete mixtures (kg/m<sup>3</sup>) |
|-----------------|---------|------------|--------------------------------------------------|
| Control sample  | 0       | 0.32       | PC 0 RHA 550 BID 510 QS 409 743 CL 5.5 176       |
| HTC-RHA -10     | 10      | 0.29       | PC 55 RHA 605 BID 510 QS 409 743 CL 5.5 176     |
| HTC-RHA -20     | 20      | 0.27       | PC 110 RHA 660 BID 510 QS 409 743 CL 5.5 176    |

<sup>b</sup> \( \frac{W}{BID} \) - the ratio water to binder and BID – bind: BID = PC + RHA.

Table 6 shows the properties of fresh concrete and samples HTC based on the compositions in Table 5, which are standardly tested and determined under normal laboratory conditions.

**Table 6.** Properties of fresh concretes and concretes

| Types of sample | Average density (kg/m<sup>3</sup>) | Slump flow (mm) | Water resistance at 28 days | Compression strength (MPa) |
|-----------------|-------------------------------------|-----------------|-----------------------------|---------------------------|
| Control sample  | 2432.5                             | 640             | 0.8                         | 29.0 44.5 61.3 70.0       |
| HTC-RHA -10     | 2448.5                             | 590             | 1.0                         | 32.4 60.2 75.3 78.2       |
| HTC-RHA -20     | 2503.5                             | 560             | 1.2                         | 38.5 61.5 79.3 80.7       |

It is known that the hydraulic constructions usually works under conditions of high groundwater pressure. They are subjected to corrode, erosion on the structural surface, leading to weakening and destruction of the constructions. Therefore, the concrete and reinforced concrete structure used for hydraulic works and hydroelectric projects are high performance concrete, which has solid microstructure, great durability, water resistance, corrosion resistance and low shrinkage [22].

The experimental method for studying the density of concrete, based on chloride-ions permeability into concrete structure is one of effective methods and has become widespread in the world, especially for the assessment of the corrosion resistance of protective concrete layer in reinforced concrete structures, which operates in seawater or in aggressive aqueous environments [23].

This study evaluated the permeability of chloride-ion in the structure of HTC samples according to ASTM C1202-97. The compositions of concrete samples were determined in Table 4.

The layout of experimental equipment arrangement and the concrete sample size used in this experimental method are shown in Fig. 3, 4 and 5.

**Figure 3.** Layout of experimental equipment and concrete sample size used to determine chloride-ion permeability according to ASTM C1202-97
This method is based on the principle of measuring the value of electrical energy transmitted through a cylindrical concrete sample with a diameter of 102 mm and a height of 51 mm in a period of 6 hours. Concrete samples were placed between the anode and the cathode as shown in Fig. 3. The 60V DC voltage is applied to two sides of the cylindrical concrete sample. In which, one side is contacted NaOH solution 0.3 N (cathode), the other is communicated in NaCl solution 3% (anode). The experimental concrete samples were conducted at the age of 28 days.

Under the influence of an electric fields, chlorine- ion diffused through the capillary pores of concrete, move from the cathode to the cathode and create an electricity. The intensity of the electric current was measured every 30 minutes for 6 hours. Further, the total of electrical energy transmitted through the concrete sample, in Coulomb (C), was calculated by the formula (1):

$$ Q = 900 (I_0 + 2I_{30} + 2I_{60} + ... + 2I_{300} + 2I_{330} + I_{360}) $$  

(1)

where: $Q$ - power transmission through the sample (C);

$I_\tau$ - the amperage at time $\tau$ (A).

The results of magnitude of amperage through the concrete samples are reported in Tables 7 - 9.

### Table 7. The magnitude of amperage through the concrete samples in the period of 6 hours according to ASTM C1202 – 97

| $\tau$ (minute) | 0  | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 | 360 |
|-----------------|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| t (°C)          | 28 | 28 | 27 | 27 | 27  | 27  | 27  | 27  | 28  | 28  | 28  | 28  | 28  |
| I (mA)          | 47.6, 47.5, 47.5, 47.3, 47.2, 47, 46.8, 46.8, 46.2, 46.8, 46 |

From the data in Table 6 and the formula (1), the average value of electrical energy transmission through the control sample in the period of 6 hours is calculated:

$$ Q_{control\ sample} = 900 (I_0 + 2I_{30} + 2I_{60} + ... + 2I_{300} + 2I_{330} + I_{360}) = 1013.22 \text{ C.} $$

### Table 8. The magnitude of amperage through the sample HTC-RHA-10 in the period of 6 hours according to ASTM C1202 – 97

| $\tau$ (minute) | 0  | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 | 360 |
|-----------------|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| t (°C)          | 28 | 28 | 28 | 28 | 28  | 28  | 28  | 28  | 28  | 28  | 28  | 28  | 28  |
| I (mA)          | 17.5, 17.2, 17.1, 16.8, 16.5, 16.2, 16, 15.8, 15.6, 15.6, 15.5, 15.3 |

Based on the data in Table 7 and the formula (1), the average value of electrical energy transmission through the sample HTC-RHA-10 in the period of 6 hours is calculated:

$$ Q_{HTC-RHA-10} = 900 (I_0 + 2I_{30} + 2I_{60} + ... + 2I_{300} + 2I_{330} + I_{360}) = 351.18 \text{ C.} $$

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**Figure 4.** Experimental concrete sample after manufacturing  
**Figure 5.** Equipment used to measure chloride-ion permeability
Table 9. The magnitude of amperage through the sample HTC-RHA-20 in the period of 6 hours according to ASTM C1202 – 97

| τ (minute) | 0   | 30  | 60  | 90  | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 | 360 |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| t (℃)     | 28  | 28  | 28  | 28  | 28  | 28  | 28  | 28  | 28  | 28  | 28  | 28  | 28  |
| I (mA)     | 0   | 14.5| 14.2| 14.2| 14  | 13.8| 13.8| 13.5| 13.5| 13.5| 13.4| 13.4| 13.3|

Based on the data in Table 8 and the formula (1), the average value of electrical energy transmission through the sample HTC-RHA-20 in the period of 6 hours is calculated:

$$Q_{HTC-RHA-20} = 900 (I_0 + 2I_{30} + 2I_{60} + ... + 2I_{330} + I_{360}) = 297 \text{ C}.$$ 

The average values of electrical energy transmission through the experimental concrete samples and the degree classification of chloride-ion permeability of concrete based on the American Concrete Association’s requirements are presented in Table 10.

Table 10. The average values of electrical energy transmission through the experimental samples and the level of chloride-ion of concrete

| Types of sample          | RHA (%) | A388 (%) | W/ BID | Average values of electrical energy (C) | Chloride-ion permeability degree of concrete |
|--------------------------|---------|----------|--------|----------------------------------------|-------------------------------------------|
| Control sample           | 0       | 1.0      | 0.32   | 1013.22                                | Low                                       |
| HTC-RHA -10              | 10      | 1.0      | 0.29   | 351.18                                 | Very low                                 |
| HTC-RHA -20              | 20      | 1.0      | 0.27   | 297                                    | Very low                                 |

It can be seen in Table 9 that the chloride-ion permeability of HTC-RHA-10 and HTC-RHA-20 samples are significantly lower than that of control concrete without RHA. The average electrical energy transmissions of the RHA-10 and RHA-20 samples are 351.18 C and 297 C, respectively, in comparison to 1013.22 C of control concrete sample. According to the classification of ASTM C1202 – 97, the chloride-ion permeability degree of this type of HTC is precisely low.

5. Conclusions

1. The use of an organic-mineral modifier based on a superplasticizer Ace 388 and a active mineral additive - RHA was leaded to the densification of the microstructure and increase the compressive strength of HTC at the age of 28 days from 11.71 to 19.1%. It was rise not only the water resistance from 25% to 50% but also the chloride-ion permeability to 2.885 times (for HTC-RHA-10 sample) and 3.41 times (for HTC-RHA-20 sample) in comparison with control concrete samples. Therefore, HTC with a modified structure from organic-mineral additive is a very promising building material and strongly effective for the construction of hydraulic structures in Vietnam.

2. Reusing of agricultural wastes (rice husk and straw) to produce concrete and other building materials will bring extremely economical and technical efficiency in Vietnam. It reduces not only the level of environmental pollution and the cost of producing construction materials, but also preserves nature materials.

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