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Characteristics of Ordinary Portland Cement Paste Containing Rice Husk Ash and Conplast [SP 430]

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ABSTRACT

An experimental investigation on rice husk ash (RHA) and Conplast SP 430 (CP-admixture) was carried out to evaluate their effects on the paste characteristics (soundness, consistency, initial and final setting times). The cement content used was 300g and the brand was ‘Ashaka’ Portland cement conforming to BS EN 12 1973. Various combinations of the mixtures OPC-RHA-CP-admixture were used to establish performance characteristics of the pastes. Statistical characteristics, and linear regression models (no-transformation, $\lambda = 0.5$, and Box-Cox transformation) were developed on the experimental data for decisions on their performances.

1. Introduction

Nigeria produces approximately 4.3 million tons of rice paddy per year. The waste is the husk has an approximate volume of 1.1 to 2 million tons per year [1,2]. These wastes can translate to tremendous wealth if properly and economically utilized mostly in our construction industry. In cement technology, this material is classified as a supplementary cementing material (SCM) or cement replacement material (CRM), as the case may be. It is also characterized as a low grade material. One of the setbacks in the use of these low grade materials is the lack of appropriate technology in processing, and the proper knowledge of its behavior when used as a composite. In this research the focus is on rice husk ash. The technology in the use of SCMs/CRMs is still at the teething stage in Africa and most specifically, Nigeria. The studies on the SCMs/CRMs have concentrated mostly on concrete oblivious of the fact that the paste in the concrete constitutes 10 to 15% of the total concrete.

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volume, and the weakest point of attack by infiltrating chemicals. The quality of the paste determines the character of the concrete. The strength of the paste, in turn depends on the ratio of water to cement. Therefore, it is very important that the characteristics of the paste is known and the processes for durable paste constituent standards strictly applied. Darweesh [3] worked on the use of black liquor waste as cement admixture or cement and concrete admixtures. Some of his conclusions showed that the water of consistency was increased by 1.68 % to 13.12 % with OPC, and by 4.11 % to 13.85 % with LPC, in comparison with those of their planks. On the other hand, the PBL waste decreased the setting times (initial or final) with either OPC or LPC. With 3 % PBL the initial and final setting times decreased from 140 to 119 min and decreased from 255 to 231 min with OPC. With LPC pastes, these changes were from 148 to 128 min and from 266 to 148 min. He therefore, concluded that setting was faster with OPC than with LPC. Hence, PBL waste can act as an accelerator for cement pastes. Habeeb and Mahmud [4] and Abubakar [5] both worked on RHA. Dobiszewska and Beycioğlu [6] researched on waste basalt powder, while Samantasingha and Singh [7] was on slag blended geopolymer paste and mortar. Understanding the underlying mechanisms of the working of these cementitious pastes are key to optimize and transit the technology to the Nigerian construction industry.

Table 1 is a collection of literature of works on paste characteristics of different types of SCMs/CRMs with and without admixtures. The collections in Table 1 show that vital information on the paste, such as cement content, water quantity or water-cementitious materials, etc. used were omitted, and therefore, points to many inherent gaps in our experiential methods and omissions of important steps. Abubakar [3] for instance, mentioned consistency as a subtitle but never highlighted anything on it. Consistency is the water affinity of the material, and very important in the classification of the material. These are some of the gaps addressed in this work. Good experimental procedures that adheres to proper code interpretations and specifications, coupled with good documentations of procedures will boost confidence in the use of these low grade materials. The study is on the paste characteristics of rice husk ash (RHA) and Conplast SP 430 [7] which are low grade materials. It is very important the RHA and CP-admixture with cement after setting, shall not undergo any appreciable change of volume to cause disruption of set and hardened mass. If this is allowed, it may cause serious difficulties for the durability of structures when such cementitious materials are used. The paste characteristics considered are soundness, consistency, and initial and final setting times. They were carried out experimentally with RHA as replacement materials in proportions of 0, 10, 20, 30, 40 and 50 % by wt. % of cement, and CP-admixture, at 5.7 mL by wt. % of cement to produce OPC-RHA-CP pastes.

| researcher | year | material | repl. (%) | mix | paste characteristics |
|------------|------|----------|-----------|-----|-----------------------|
| Elniwa and Mahmood [1] | 2002 | sawdust ash | 0 | cement (g), cement type, water (kg/m³), admixture type, dosage | setting (min), contcy (%), initial setting (min), final setting (min) |
|         |      |          | 5 | *0.32, nil | 0.70, - ,116, 241 |
|         |      |          | 10 | *0.34 | 0.75, 118, 247 |
|         |      |          | 15 | *0.35 | 1.00, 128, 267 |
|         |      |          | 20 | *0.37 | 1.15, 135, 283 |
|         |      |          | 25 | *0.39 | 1.25, 160, 298 |
|         |      |          | 30 | *0.42 | 1.30, 170, 318 |
|         |      |          | 35 | 1.45 | - , 190, 337 |
| Samantasinghar and Singh [8] | 2019 | GGBS | 0 | cement (g), cement type, water (kg/m³), admixture type, dosage | setting (min), contcy (%), initial setting (min), final setting (min) |
|         |      |          | 20 | *0.34 | 39, 700, 1525 |
|         |      |          | 40 | *0.37 | 38, 180, 400 |
|         |      |          | 60 | *0.39 | 36, 80, 100 |
|         |      |          | 80 | *0.42 | 34, 50, 80 |
|         |      |          | 100 | 1.45 | 32, 25, 50 |
|         |      |          | 150 | 1.50 | 31, 20, 20 |
| Alkheider et al [9] | 2016 | Olive waste husk | 0 | cement (g), cement type, water (kg/m³), admixture type, dosage | setting (min), contcy (%), initial setting (min), final setting (min) |
|         |      |          | 3 | 165.0, 160.8 | 160.8, 378 |
|         |      |          | 6 | 159.1, 181.9 | 210.3, 383 |
|         |      |          | 9 | 156.3, 221.6 | 221.6, 387 |
|         |      |          | 12 | 152.2, 227.4 | 227.4, 389 |
|         |      |          | 15 | 148.6, 231.0 | 231.0, 391 |
| Researcher          | Year | Material    | Repl. (%) | Mix | Paste Characteristics |
|---------------------|------|-------------|-----------|-----|-----------------------|
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0   | 180 250               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.3 | 310 490               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.4 | 340 500               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.5 | 390 590               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.6 | 210 605               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.7 | 150 600               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.8 | 240 500               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.9 | 100 495               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 1.0 | 90   490               |
| Mbugua et al        | 2016 | Gum Arabic  | 0-1.0    | 0   | 180 250               |
| Mbugua et al        | 2016 | Gum Arabic  | 0-1.0    | 0.3 | 440 660               |
| Mbugua et al        | 2016 | Tard CE      | 0.4-0.7  | 0   | 180 250               |
| Mbugua et al        | 2016 | Tard CE      | 0.4-0.7  | 0.3 | 440 660               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.4 | 330 795               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.5 | 325 796               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.6 | 320 800               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0.7 | 320 800               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 0   | 140 174               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 1   | 150 167               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 2   | 142 225               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 3   | 164 225               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 4   | 146 228               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 5   | 164 249               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 6   | 166 232               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 7   | 170 265               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 8   | 188 272               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 9   | 193 276               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 10  | 190 288               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 1   | 186 287               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 2   | 190 289               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 3   | 201 291               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 4   | 203 296               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 5   | 202 311               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 6   | 222 311               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 7   | 230 305               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 8   | 226 308               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 9   | 226 308               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 10  | 226 308               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 1   | 235 288               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 2   | 192 302               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 3   | 203 330               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 4   | 246 324               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 5   | 215 332               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 6   | 205 329               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 7   | 200 344               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 8   | 220 335               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 9   | 225 340               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 10  | 218 353               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 1   | 236 349               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 2   | 232 372               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 3   | 191 246               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 4   | 185 252               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 5   | 180 258               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 6   | 207 253               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 7   | 205 260               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 8   | 192 267               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 9   | 207 265               |
| Dobiszewska         | 2017 | Basalt powder | 3-10     | 10  | 202 262               |
2. Materials

The materials used are Ashaka Portland cement, rice husk ash and Conplast SP 430 as the plasticizer. The cement conforms to BS EN 197 Part 1 [13], and was procured at the local market in Bauchi, Nigeria. The rice husk ash used for the production of the ash was collected as a waste threshed out and separated from the rice grains. Therefore, it was collected as a waste and calcined in the kiln of the Industrial Department of the university at a temperature range of 400 °C to 600 °C, grinded using pestle and mortar, and sieved using a sieve size of 150 µm. The physical and chemical properties were carried out in accordance with ASTM C 618-12 [14]. The cement chemical properties were tested at Ashaka Cement Company in Ashaka, Gombe State. The physical and chemical properties of the ‘Ashaka’ OPC and RHA are shown in Table 2.

Table 2. Physical and Chemical Properties of Ashaka Portland Cement and Rice Husk Ash

| Parameter                  | Cement          | Rice Husk Ash |
|----------------------------|-----------------|---------------|
| Specific gravity           | 3.12            | 1.934         |
| Fineness (kg/m²) [ref]     | 330             | 20.2 (%)      |
| Bulk density (kg/m³)       | 830-1650        |               |
| Consistency (%)            | 29              |               |
| Initial setting time (min) | 65              |               |
| Final setting time (min)   | 275             |               |
| Soundness (mm)             | 2.5             |               |
| LOI                        | -               | 7.0           |

| Parameter                | Description                                                                 |
|--------------------------|-----------------------------------------------------------------------------|
| Appearance               | Brown liquid                                                                 |
| Specific gravity         | 1.18 @ 25°C                                                                  |
| Chloride content         | Nil to BS 5075/BS: EN934                                                    |
| Air entrainment          | Less than 2 % additional air is entrained at normal dosages                  |

3. Experiment

The soundness, standard consistency and initial and final setting times were carried out using ordinary Portland cement (OPC) paste containing rice husk ash (RHA) and Conplast SP 430 (CP-admixture) in proportions of 0, 10, 20, 30, 40, and 50 %, respectively. The control mix was designated as MR-00, reflecting a paste without RHA or CP-admixture. The other paste compositions are labelled as MR-10/50 for OPC-pastes containing RHA only, and MRCP-10/50 for OPC-pastes containing both RHA and CP, respectively. A cement content of 300 g was used with RHA replacements of cement by wt. %, and/or, with a CP-admixture dosage of 5.7 mL wt. % of cement. These mixes were used to study their effects on the soundness, consistency and initial and final setting times.

Soundness of cement is a quality assurance test of cement. This was carried out to examine expansion due to the presence of free lime and magnesia (MgO) in the cement. This is important to affirm that the cement after setting shall not undergo a large expansion to cause...
disruption of the cement used. It was carried out using the Le-Chateliers apparatus and consists of a small split cylinder of spring brass to other non-corrodible metal of 0.5 mm thickness forming a mold of 30 mm internal diameter and 30 mm high. On either side of the split, two indicators are brazed suitably with pointed ends made of 2 mm diameter brass wire in such a way that the distance of these ends to the centre of the cylinder is 165 mm. The split cylinder was kept between two glass plates and the temperature in the laboratory was almost 29°C, and the relative humidity was 62 %. The immersed Le-Chatelier molds were raised to a temperature of approximately 27 °C, and measured with a Vernier caliper.

The consistence of a binder paste is the measure of the degree of wetness or fluidity of the prepared paste. The objective of conducting this test is to find out the amount of water needed to be added to the cement to get a paste of normal consistence. It is defined as that consistence that will permit the Vicat plunger to penetrate to a point 5 to 7 mm from the bottom of the Vicat mold. Pastes with the above compositions were used for this test. The precaution taken was that gauging was kept below 5 min to avoid setting before time. The test was conducted in accordance with BS 4550: 1978 [16] specification, and evaluated using Equation (1):

\[
\text{Standard Consistency (\%)} = \frac{\text{Weight of water added}}{\text{Weight of cementitious material}} \times 100 \tag{1}
\]

The initial setting time is the time when cement paste starts hardening while the final setting time is the time when cement paste has hardened sufficiently in such a way that a 1 mm needle makes an impression on the paste in the mold but 5 mm needle does not make any impression. Setting time is the time required for stiffening of cement paste to a defined consistence, and thus initial setting time is important for transportation, placing and compaction of cement concrete. It is required to delay the process of hydration or hardening. The Vicat’s apparatus was used for this test and conducted in accordance with BS 12; [1] and BS 4550 [16] specifications respectively. The initial and final setting times of the paste are shown in Table 4.

\[
\text{Initial Setting Time} = T_2 - T_1 \\
\text{Final Setting Time} = T_3 - T_1
\tag{2}
\]

Where,

- \( T_1 \)= Time at which water was first added to cement
- \( T_2 \)= Time when needle failed to penetrate 5 mm to 7 mm from bottom of the mold
- \( T_3 \)= Time when the needle made an impression but the attachment failed to do so.

The results of the soundness, consistence and initial and final times of setting are shown in Table 4.

### Table 4. Soundness, Consistency and Setting Times of RHA-CP-OPC Paste

| Mix No | Complast (mL) | Soundness (mm) | Consistency (%) | Setting Times (Min) |
|--------|---------------|----------------|-----------------|--------------------|
|        |               |                |                 | Initial | Final  |
| MR-00  | Nil           | 7.0            | 36.0            | 120.0   | 180.0  |
| MR-10  | Nil           | 8.0            | 39.0            | 130.0   | 219.0  |
| MR-20  | Nil           | 8.0            | 55.0            | 152.0   | 249.0  |
| MR-30  | Nil           | 10.0           | 58.0            | 160.0   | 271.0  |
| MR-40  | Nil           | 10.0           | 101.0           | 210.0   | 345.0  |
| MR-50  | Nil           | 10.0           | 112.0           | 276.0   | 397.0  |
| MRC-00 | 5.7           | 9.0            | 34.0            | 128.0   | 186.0  |
| MRC-10 | 5.7           | 9.3            | 37.0            | 137.0   | 225.0  |
| MRC-20 | 5.7           | 9.7            | 50.0            | 159.0   | 258.0  |
| MRC-30 | 5.7           | 9.9            | 55.0            | 166.0   | 278.0  |
| MRC-40 | 5.7           | 9.8            | 60.0            | 216.0   | 352.0  |
| MRC-50 | 5.7           | 9.5            | 65.0            | 284.0   | 405.0  |

### Table 5. Percentage Difference of OPC-RHA-CP Paste

| Mix- | Replacement | Soundness  | Consistency | Initial Setting | Final Setting |
|------|-------------|------------|-------------|-----------------|---------------|
| Control Paste with CP (MR-00 and MRC-00) – Mix 0  | 0.00 | 28.6 | -5.6 | 6.7 | 3.3 |
| Control paste with RHA and paste | 10 | 14.3 | 8.3 | 8.3 | 21.7 |
| 20 | 14.3 | 52.8 | 26.7 | 38.3 |
| 30 | 42.9 | 61.0 | 33.3 | 50.6 |
| (MR-00 and MR-10, 20, etc) – Mix 1 | 40 | 42.9 | 180.6 | 75.0 | 91.7 |
| 50 | 42.9 | 211.1 | 130.0 | 120.6 |
| Control Paste with CP and RHA with CP | 10 | 3.3 | 8.8 | 7.0 | 21.0 |
| 20 | 7.8 | 47.1 | 24.2 | 37.7 |
| (MRC-00 and MRCP-10, 20, etc) – Mix 2 | 30 | 10.0 | 61.8 | 29.7 | 49.5 |
| 40 | 8.9 | 76.5 | 68.8 | 89.2 |
| 50 | 5.6 | 91.2 | 121.9 | 117.7 |
| Paste with RHA and RHA paste with CP | 10 | 16.3 | -5.1 | 5.4 | 2.7 |
| 20 | 21.3 | -10.0 | 4.6 | 3.6 |
| (MR-10, 20, etc) – Mix 3 | 30 | -1.0 | -5.5 | 3.8 | 2.6 |
| 40 | -2.0 | -40.6 | 2.9 | 2.0 |
| 50 | -5.0 | -42.0 | 2.9 | 2.0 |

### 4. Discussion

What gives cement it’s property is the CaO content and it has a cementing property. This is approximately 61 %. The SiO₂ in the cement is only approximately 20 %. However, for the RHA the SiO₂ is 74 % and the CaO is just approximately 1 %. The sum of the SiO₂ + Al₂O₃ + Fe₂O₃ in the RHA is approximately 82 %, which is greater
than the 70% specified in ASTM for pozzolanicity. The limits of the MgO and Na₂O both in the cement and RHA are 0.97/0.12 and 2.43/0.90. These are both less than the limits set for them by BS 12 (1999), that is 0.1 to 4.0 and 0.2 to 1.3, respectively. Can be said to be okay. The K₂O content and the LOI are 2.8% and 7% respectively. A well burnt RHA has an average composition 2% K₂O and 5% carbon (LOI). Therefore, within the experimental errors the RHA can be said to be okay.

Figures labeled 3a and 4a are plots of the data on paste characteristics of the OPC-RHA-CP-admixture cement paste, while Figures 3b and 4b are plots taken from Table 5 showing the percentage differences recorded for each mix combinations (Mix 0 to Mix 3). The performances of these pastes reflect the characteristics of the RHA which are dependent on three factors: (i) the composition of the rice husk, (ii) the burning temperature and, (iii) the burning time. Under controlled burning conditions (as in this case) the volatile organic matter in the rice husk consisting of cellulose and lignin are removed and the residual ash is predominantly amorphous silica with a (microporous) cellular structure as shown in Figures 1 and 2, the microstructure and diffractogram of the RHA.

The soundness of the OPC-RHA-CP paste is shown in Figure 3. It shows that for all combinations of the paste the soundness was ≤10%. Therefore, it can be said that the addition of RHA and/or CP-admixture to OPC paste will not cause unsoundness and after setting will not undergo any appreciable change of volume. The addition of 5.7 mL of CP-admixture by wt.% of cement to OPC increased the soundness by approximately 28%. The difference between the control mix (MR-00) and the mix containing RHA (MR-10 to MR-50) without CP-admixture showed an increase of 14.3% at 10 and 20% replacements respectively, and remained constant at 42.9% at 30 to 50% replacements. The same comparison is made for the case when the control paste containing CP-admixture (MRCP-00) and that containing RHA with CP-admixture (MRCP-10 to MRCP-50). The comparison shows increases of 3.3 at 10% with a peak value of 10% at 30% replacement, and fell to a value of 5.6% at 50% replacement. However, the case of adding CP-admixture to MR-00 and MR-10 to MR-50, and compared shows that it has drastic effects at higher replacement levels of RHA. At 10 to 20% replacements there were increases of 16.3% and 21.3% respectively, but drastically reduced from 30 to 50% replacements to -1.0 to -5.0%.

Figure 1. Micrograph of RHA

Figure 2. XRD Diffractogram of RHA

Figure 3. Soundness of RHA-CP-OPC Paste

Figure 4 is the consistency of OPC-RHA-CP cement paste. The consistency is the water affinity of the cementitious material. This decreased by 5.6% when CP-admixture was added to the control mix (MR-00).
One of the advantages of water reducing admixture such as naphthalene sulphonated is that it reduces the water-cementitious ratio while keeping the concrete workable. For the mix without the CP-admixture (MR-00 and MR-10 to MR-50) the water requirement increased from 8.3 to 211.1 %. RHA contains a cellular, honeycomb morphology of amorphous silica and this morphology results in high water absorption. Therefore, the increase in water affinity can be attributed to this rough texture and amorphous nature of the RHA. We therefore, need more water for workability. This behavior is further confirmed for the same mix but with CP-admixture (MRCP-00 and MRCP-10 to MRCP-50 where the water for workable OPC paste decreased from 8.8 to 91.2 %.

![Figure 4. Consistency of RHA-CP-OPC Paste](image)

Statistical Characteristics and Linear Regression Model of OPC-RHA-CP Paste

Table 6 shows the statistical characteristics of the paste. It shows the mean, standard deviation etc of the paste. The mean value characterizes the central tendency or location of the data, while the coefficient of variation provides a general feeling about the performance of the method. It is the distribution of data points in a data series around the mean and thus, expresses the variation as a percentage of the mean. The larger the coefficient of variation, the greater the spread in the data. The standard error of the mean (SE Mean) estimates the variability between sample means, and the standard deviation and thus, establishes a benchmark for estimating the overall variation of a process. Whereas the standard error of the mean estimates the variability between samples, the standard deviation measures the variability within a single sample. A higher standard deviation value indicates greater spread in the data. From the results are achieved in Table 6 it can be concluded that both the RHA and CP-admixture are
compatible with the ‘Ashaka’ Portland cement.

**Table 6. Statistical Characteristics of OPC-RHA-CP Paste**

| Mix   | Variable     | Mean | SE Mean | StDev | Variance | CoefVar |
|-------|--------------|------|---------|-------|----------|---------|
| RHA   | Soundness    | 8.8  | 0.5     | 1.33  | 1.8      | 15.1    |
|       | Consistency  | 66.8 | 13.1    | 32.1  | 1030.2   | 48.0    |
|       | Initial Setting | 174.7 | 58.7    | 58.7  | 3445.9   | 33.6    |
|       | Final Setting | 276.7 | 80.9    | 80.9  | 6546.7   | 29.3    |
| RHA-CP| Soundness    | 9.5  | 0.1     | 0.3   | 0.1      | 3.6     |
|       | Consistency  | 50.2 | 5.1     | 12.5  | 155.0    | 24.8    |
|       | Initial Setting | 181.7 | 24.0    | 58.8  | 3457.1   | 32.4    |
|       | Final Setting | 284.0 | 33.2    | 81.3  | 6612.4   | 28.6    |

Tables 7 and 8 are the linear regression model characteristics of the OPC-RHA-CP-admixture paste. The study on the experimental data used three regression models: (i) no-transformation, (ii) \( \lambda = 0.5 \) transformation, and (iii) box-cox transformation. The model characteristics are shown in the Tables 7 and 8, respectively, and the normality plot for the various mixes shown in Figure 7. All the models used seem to be adequate but the box-cox transformation shows more appropriateness compared with the no-transformation and \( \lambda = 0.5 \), based on the quality of the regression model characteristics achieved.

**Table 7. Model Characteristics of OPC-RHA Paste**

| Parameter                  | RHA-OPC Paste Characteristics |
|----------------------------|-------------------------------|
|                           | MODEL I                       | MODEL II                      | MODEL III                      |
| Regression                | \( p = 0.040 \)               | \( 0.035 \)                   | \( 0.034 \)                    |
| Soundness                 | \( p = 0.550 \)               | \( 0.561 \)                   | \( 0.604 \)                    |
| Initial Setting           | \( p = 0.773 \)               | \( 0.598 \)                   | \( 0.465 \)                    |
| Final Setting             | \( p = 0.285 \)               | \( 0.225 \)                   | \( 0.192 \)                    |
| Constant                  | \( p = 0.678 \)               | \( 0.305 \)                   | \( 0.029 \)                    |
| Model Summary             | \( S(8.2782); R^2(97.3\%); R^2\text{(pred)}(84.2\%) \) | \( S(0.4630); R^2(97.7\%); R^2\text{(pred)}(97.7\%) \) | \( S(0.1128); R^2(97.72\%); R^2\text{(pred)}(93.3\%) \) |
| Transformation            | None                          | \( \lambda = 0.5 \)          | \( \lambda = 0.0235 \)         |
|                           | estimated \( \lambda = -0.866784 \) | \( 95 \% \text{ CI for } \lambda = (-1.2430, 1.3850) \) |

**Table 8. Model Characteristics of OPC-RHA-CP Paste**

| Parameter                  | RHA-OPC Paste Characteristics |
|----------------------------|-------------------------------|
| Regression                 | \( p = 0.009 \)               | \( 0.007 \)                   | \( 0.004 \)                    |
| Soundness                  | \( p = 0.043 \)               | \( 0.031 \)                   | \( 0.014 \)                    |
| Initial Setting            | \( p = 0.124 \)               | \( 0.103 \)                   | \( 0.067 \)                    |
| Final Setting              | \( p = 0.362 \)               | \( 0.300 \)                   | \( 0.179 \)                    |
| Constant                   | \( p = 0.046 \)               | \( 0.305 \)                   | \( 0.029 \)                    |
| Model Summary              | \( S(1.5141); R^2(99.9\%); R^2\text{(pred)}(84.2\%) \) | \( S(0.0996); R^2(99.5\%); R^2\text{(pred)}(86.1\%) \) | \( S(0.1128); R^2(97.72\%); R^2\text{(pred)}(93.3\%) \) |
| Transformation             | None                          | \( \lambda = 0.5 \)          | \( \lambda = -0.866784 \)      |
|                           | estimated \( \lambda = -0.866784 \) | \( 95 \% \text{ CI for } \lambda = (-2.31928, 1.46672) \) |
5. Conclusions

An experimental investigation of the effects of using supplementary cement materials (SCM), in this case RHA, and an admixture, (Conplast SP 430) which is plasticizer, to evaluate the paste characteristics of mixes made with and without RHA, and CP-admixture as the case may be. The conclusions are:

i. RHA is pozzolanic and the limits of MgO and Na₂O are within the code’s specifications. Using RHA, and/or RHA with CP-admixture will not cause unsoundness, and will not undergo any appreciable change after setting.

ii. A mixture of RHA alone will increase the water requirement because of the morphology of the RHA which encourages water absorption.

iii. Addition of CP-admixture to RHA mix will reduce the water affinity of RHA.

iv. The setting times will be affected by both the addition of RHA and CP-admixture which will allow adequate time for concreting before it sets.

Recommendation

The use of RHA with CP-admixture is recommended for good flow of the paste.

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