ABSTRACT: The high cement content (900-1000 kg/m³) used to produce Ultra High Performance Concrete (UHPC) causes some disadvantages from the sustainability development point of view. This paper presents the significance of using an agricultural waste, rice husk ash (RHA) as a cement replacement material in producing UHPC. The interesting point is that the total cement replacement by blending of RHA, silica fume and blast furnace slag can reach to 75% by weight, or only 300 kg/m³ clinker used to make UHPC. This contributes greatly to the sustainable development and economic benefits for concrete industry, especially in developing countries.

1 INTRODUCTION

Pozzolans are powders used in concrete in relatively large amounts and mainly used as cement replacements in order to enhance early and long term performance. The use of these materials reduces the cost of concrete production and environmental benefits. Regarding to the sustainable development in relationship with concrete technology, the American Concrete Institute Board of Direction formed a Task Group with a mission “to encourage development and application of environmentally friendly, sustainable concrete materials, design, and construction” (Malhotra 2002). Mehta (2009) suggested three tools which the concrete industry can use to attain sustainability including (1) consume less concrete; (2) consume less cement in concrete mixtures by specifying 56- or 90-day compressive strength, or by using water-reducing admixtures, or by optimizing aggregate size and grading; and (3) consume less clinker in cement by using a high volume of one or more cementitious materials such as fly ash, slag, silica fume, etc. In this paper the third tool was considered, in which the use of rice husk ash (RHA) to produce Ultra High Performance Concrete (UHPC) for sustainable development was investigated.

UHPC refers to concrete with superior mechanical properties and very high durability due to its dense microstructure. The compressive and flexural-tensile strengths of UHPC have been proved to be over 150 MPa and 20 MPa, respectively (AFGC-SETRA 2002). Normally, the UHPC is made using sand, silica fume, very low amounts of water, and high amounts of cement. In fact, the water to binder (w/b) ratio of UHPC is very low, from 0.10 to 0.25 by weight (Vande Voort et al. 2008). The final hydration degree of cement in UHPC was estimated ranging from 31 to 60% (Cheyrezy et al. 1995; Habel et al. 2006). The anhydrous cores of cement particles then work as micro-aggregates. It means that being a very expensive "filler", the substitution of cement by mineral admixtures is desirable. The non-hydrated cement particles, together with the finer particles of pozzolans give a larger packing effect and increase the strength and durability. In effect, the smaller particles (<5 μm) promote larger intermolecular attraction (Van der Waals forces) acting as molecular polarization agents (zeta potential) (Isaia 1999). Moreover, because of a very high cement content (900-1000 kg/m³) used in UHPC (Richard and Cheyrezy 1995), the substitution of cement by mineral admixtures will also give rise to many other beneficial effects that improve the environment and lead to enhanced sustainability of UHPC. In this respect, the maximum
cement replacement content by these mineral admixtures should be evaluated.

This paper presents the use of RHA as a cement replacement material in combination with and without silica fume (SF) to produce UHPC for sustainable development.

2 MATERIALS AND METHODS

2.1 Materials

The materials used in this study were silica sand with a mean particle size of 225 \( \mu m \), Portland cement (CEM I 52.5N) with a Blaine specific surface area of 4500 \( cm^2/g \), condensed SF, RHA, and polycarboxylate based superplasticizer with 30% solid content by weight. The SF has an amorphous SiO\(_2\) content of 97.2% and its mean particle size is about 0.1 - 0.15 \( \mu m \). The particle size distribution and the mean particle size of materials in this study were determined by laser diffraction.

Rice husk, from Vietnam, was burnt in a drum incinerator developed by Pakistan Council of Scientific & Industrial Research (Cook 1984) under uncontrolled combustion conditions. Details of the oven and rice husk combustion process were described elsewhere (Bui 2001). The obtained ash was ground in a vibrating ball mill for 90 minutes. The ash contains 87.96% amorphous SiO\(_2\), 3.81% loss on ignition and its mean particle size is 5.6 \( \mu m \). The particle size distribution of these materials is shown in Figure 1.

![Figure 1. Particle size distribution of materials used in this study](image)

2.2 Packing density and mix composition

Optimization of granular mixture is one of the key issues in UHPC mix design. The optimization of granular mixtures in this study was achieved by using the packing model developed by de Larrard and Sedran (1994) with the compaction index of 12.5 (Jones et al. 2002). The granular mixture was considered as a ternary system of sand, cement and RHA in which the RHA content was fixed at 20% by weight of binder (cement and RHA). The optimized packing of this ternary system was calculated at sand to binder ratio of 1. The w/b ratio of UHPC was fixed at 0.18. Finally, the mix composition of UHPC was prepared as shown in Table 1, in which SF was also used to compare to RHA.

2.3 Methods

All materials were prepared in a 20-liter Hobart mixer. The volume of each batch was 3.5 liters. Figure 2 shows the mixing procedure.
Table 1. Mix composition of UHPC

<table>
<thead>
<tr>
<th>Water to binder ratio (by weight)</th>
<th>Sand to binder ratio (by weight)</th>
<th>RHA (% by weight)</th>
<th>SF (% by weight)</th>
<th>Type of cement</th>
<th>Amount of superplasticizer (% solid by weight of binder)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.18</td>
<td>1</td>
<td>0-10-20-30</td>
<td></td>
<td>CEM I 52.5 N</td>
<td>0.90-1.00-1.20-1.76</td>
</tr>
<tr>
<td>0.18</td>
<td>1</td>
<td>10-20-30-40</td>
<td></td>
<td>CEM I 52.5 N</td>
<td>0.63-0.76-1.43-2.28</td>
</tr>
<tr>
<td>0.18</td>
<td>1</td>
<td>10-20-30-40</td>
<td>10</td>
<td>CEM I 52.5 N</td>
<td>1.00-1.22-1.70-2.70</td>
</tr>
<tr>
<td>0.15</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>CEM I 52.5 N</td>
<td>1.85</td>
</tr>
<tr>
<td>0.15</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>CEM III/B 42.5 N</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Figure 2. Mixing procedure for UHPC

The workability of mixtures was determined by means of flow table test. The flow measurements were kept between 210 and 230 mm. Mixtures were cast into the 40×40×40 mm³ cubes for the compression test. All mixtures were vibrated for 1 minute using a vibration table with a frequency of 2500 cycles/min. After casting, samples were cured in a fog room (20±2°C, RH>95%) for one day. After demoulding, the samples were still stored in the fog room until the day of testing.

3 RESULTS AND DISCUSSION

3.1 Workability of UHPC mixtures

The amount of superplasticizer used in the mixtures is presented in Table 1. It can be seen that with the cement replacement percentage less than 20%, the addition of RHA decreases workability of mixtures and vice versa in case of SF. When more cement was replaced by RHA or SF, i.e. beyond 30%, the amount of superplasticizer increases significantly. This is due to the high water demand of RHA by its cellular porous structure (Bui 2001) which absorbs a certain amount of the mixing water. The improvement of the workability of UHPC mixtures by the addition of SF may be attributed to fine spherical particles of SF, which act as a lubricant. However, with a higher SF content, the total surface area contributed from the ultra fine particles increases dramatically. This will increase the water demand and may not be compensated by the 'lubricant effect' of SF.

From this result, it gives rise to an idea that RHA may be used to combine with SF to offset the reduction of the workability of the RHA mixtures. Indeed, the amounts of superplasticizer of the RHA mixtures were not increased with addition of 10% SF. Moreover, the maximum content of cement replacement by the combination of RHA and SF can be increased to 50% whereas the maximum cement replacement contents are only 30% and 40% for the RHA mixtures and the SF mixtures, respectively.

Because the high amount of superplasticizer used in the concrete mixtures, this will delay the setting of cement. Therefore, the cement replacement contents by 20% RHA, 30% SF, and 40% blend of RHA and SF, respectively, were considered as the "maximum" cement replacement levels in this study.
3.2 Effect of the RHA content on the compressive strength of UHPC

In this part, the possibility of using RHA to make UHPC was investigated. The compressive strength of RHA samples were compared to that of the SF samples at 28 days as shown in Figure 3. It can be seen that the compressive strength of UHPC increases with the addition of RHA. The highest compressive strength of the RHA samples was achieved with an addition of 20% RHA. This result is significantly higher than that of the control sample containing 0% RHA or 0% SF. Although the compressive strength of the RHA sample increased with increasing of the RHA content, the use of a high amount of superplasticizer needed to control the workability of UHPC mixtures will delay the setting of cement as above mentioned. Therefore, the RHA content of 20% was considered as a maximum cement replacement level.

![Figure 3. Compressive strength of UHPC samples vs. % RHA and % SF at 28 days, w/b ratio = 0.18](image)

Compared to the RHA samples, the highest compressive strength of the SF samples was attained at a cement replacement level by 10% SF. Besides, the addition of 10% SF strongly improves the workability of UHPC mixtures (Table 1). Therefore, this content was fixed in order to study the effect of the combination of RHA and SF on the compressive strength of UHPC.

3.3 Effect of the combination of RHA and SF on the compressive strength of UHPC

The effect of combination of RHA and SF on the 28-day compressive strength of UHPC was studied with RHA contents in the range from 10 to 30% and a fixed SF content of 10%. The result is shown in Figure 4. It is clear that in combination with 10% SF, the RHA content used to make UHPC can be possibly increased to 30%. The compressive strength of all samples is in excess of 150 MPa. Therefore, in this case the total cement replacement by using the blend of RHA and SF can reach to 40% in which the SF content is 10%.

![Figure 4. Compressive strength of UHPC samples vs. % blend of RHA and SF at 28 days, w/b ratio = 0.18](image)

3.4 Effect of the blend of RHA and SF in combination with using the slag cement on the compressive strength of UHPC

As observed from both Figure 3 and Figure 4, the sample made with the combination of 10% RHA and 10% SF gives a highest compressive strength compared to that of the control sample and samples using other blends. From this result, a further investigation of using this combination in making UHPC was performed in order to increase the total cement replacement content.

It is well-known that the addition of some very fine powders such as blast furnace slag (Lange et al.
1997) and fly ash (Ferraris et al. 2001), can improve the workability of fresh concrete. This gives rise to an idea that the content of cement replacement can be expected to increase further by the addition of these powder additions. Blast furnace slag-blended cement, a composition of ground slag Portland clinker and gypsum/anhydrite, is in common use in Netherlands (Bijen 1996) and the type of cement CEM III/B 42.5 N comprising 69% weight relative to a total weight of slag cement was chosen in order to increase the total content of cement replacement. The fineness of this cement is similar to that of cement I 52.5 N, thereby the change of type of cement does not influence the optimization of the packing density of the granular mixture (as seen in Figure 5) and on the resulting mix composition. As expected, the experimental results (Table 1) clearly show that the workability of the CEM III/B 42.5 N mixture was much improved compared to that of the CEM I 52.5 N mixture. Only half the amount of superplasticizer was needed to achieve the required flow value compared to that of the CEM I 52.5 N mixture.

![Figure 5 Calculated packing density of granular mixtures with different types of cement](image1)

![Figure 6. Compressive strength of UHPC samples using blend of 10% RHA and 10% SF in combination with using slag cement vs. time, w/b ratio = 0.18](image2)

Figure 6 shows the results of compressive strength of UHPC made with two types of cement versus time. It can be seen that the compressive strength of the sample using cement CEM III/B 42.5 N was relatively low at the first day. However, after 3 days, the compressive strength of this sample does not show a big difference compared to that of the sample using cement CEM I 52.5 N. It should be noted that the 28-day compressive strength of both samples was in excess of 150 MPa.

Owing to the fact that the slag cement CEM III/B 42.5 N contains 69% blast furnace slag and the total blend of RHA and SF of 20% was used in this case, the total content of cement replacement of about 75% can be possibly attained.

4 DISCUSSIONS

In this work, the possibility of using RHA in combination with and without SF to produce UHPC was investigated. The effect of RHA on compressive strength of UHPC can be explained firstly by the improvement of packing density of system. The mean particle size of RHA is 5.6 μm, which is smaller than that of the cement particle size (10-15 μm). Therefore, the mixtures become denser with the addition of RHA.

Second, because of its porous structure, RHA has a very large specific surface area. The pores of RHA may absorb a certain amount of free water. This water is then released from these pores when the relative humidity in the paste decreases with progress of the cement hydration process, and therefore increases the hydration degree of blended cement. The previous work (Nguyen et al. 2010) shows that in low w/b ratio mixtures, the addition of RHA increases the degree of blended cement hydration at the later period. This suggests a mechanism which is similar to that proposed by Weber and Reinhardt (1997) and Breugel et
when using the water saturated lightweight aggregates or proposed by Jensen and Hansen (2001; 2002) when using SAP particles for internal curing of concrete.

Furthermore, as RHA may absorb a certain amount of mixing water in its pores, the w/b ratio of RHA mixtures is lower than that of the control mixture. This can result in a higher strength in this case.

5 Conclusions

This paper presents the possibility of using RHA in combination with and without SF to make UHPC in order to get the benefits in terms of the cost and the sustainability. Following conclusions can be drawn:

- RHA can be used to make UHPC without decreasing the compressive strength compared to that of the control sample in which the maximum RHA content is 20% by weight of binder.
- The combination of RHA and SF can increase the maximum content of total cement replacement to 40%, in which the RHA content is 30% by weight of binder.
- The blend of 10% RHA and 10% SF can be used to make UHPC with an increase the total cement replacement content to about 75% by weight of binder by using in combination with the cement CEM III/B 42.5 N.

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