ULTRA HIGH PERFORMANCE CONCRETE MADE WITH RICE HUSK ASH FOR REDUCED AUTOGENOUS SHRINKAGE

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Abstract

Ultra High Strength Concrete (UHPC) is generally made with low w/c mixtures and by adding silica fume. Low w/c mixtures, however, exhibit high autogenous shrinkage, while a high amount of silica fume increases the price of these mixtures. For designing ultra high strength mixtures with low autogenous shrinkage and lower costs the possibility of using rice husk ask (RHA) as alternative for silica fume has been studied. The use of RHA as replacement of cement is well known, but the application of this material for (ultra) high strength mixtures has hardly been considered yet.

In this paper the results are shown of an extensive study of the compressive strength of UHPC made with partial replacement of cement by RHA. The mean size of the RHA particles varied from 3.6 μm and 9 μm. Samples with a combination of 10% RHA and 10% SF showed higher compressive strength than the control samples with either 20% RHA or 20% SF as cement replacement. This blend proved to be the optimum combination for achieving maximum synergic effect. Due attention is given in this paper to the observation that the use of RHA resulted in a substantial reduction of autogenous shrinkage compared to UHPC mixtures made with silica fume.

Keywords: Autogenous Shrinkage, Rice Husk Ash, Strength, Ultra High Performance Concrete

1 Introduction

The high impact of the building industry on the environment has stimulated engineers and scientists to search for alternative building materials and innovative construction methods. More recently new and more stringent legislation has further increased the pressure on the building industry to reduce materials and energy consumption, as well as the emission of CO_2. One way to achieve these goals is the use of high strength materials, like Ultra High Performance Concrete (UHPC). Because of its superior mechanical properties, reductions of the dead weight of structures can be achieved, foundations can be made cheaper and the net m^2 floor area remains higher. Moreover, the high density of the material is considered favorable for the structure's durability.

The high density and high strength of UHPC are realized by using a low water-binder (w/b) ratio and, very often, the use of silica fume. Silica fume, because of its extreme fineness (mean particle size of 0.1-1 μm (Malhotra et al., 1987)), fills up the voids between the coarser cement grains, thus increasing the packing density of the cement paste and of the interfacial aggregate-paste zone in particular. Apart from its filler effect, silica fume also contributes to the strength of the material because of its pozzolanic properties. Its high specific surface further contributes to its reactivity.

An often mentioned drawback of the use of silica fume is its high price. This is one of the reasons why countries, which have to import silica fume from abroad, are in search for cheaper alternatives. A promising alternative for SF is rice husk ash (RHA), an agricultural waste product. Rice husk ash is available in large quantities in countries where rice is the main food. The RHA constitutes about 4% of the 720 million metric tons of rice paddy produced annually worldwide (FAO, 2012). The ash, obtained after complete combustion of the husk in controlled conditions, contains 90-96% silica in an amorphous form. This ash was found to be highly pozzolanic and, therefore, an excellent supplementary cementing material, comparable to that of SF (Mehta, 1994).

The use of RHA as replacement for cement is known for many years already (e.g. Nair, 2006). However, its use as replacement of silica fume for production of UHPC is new and, at first sight, a bit surprising. From the chemical point of view the materials exhibit much similarity with SF. The structure of the particles, however, is completely different. Silica fume particles are spherical, whereas RHA particles are porous, have an irregular shape, generally ground to a size between 5 µm to 10 µm (Diddique, 2008). Hence, RHA is not an ultra-fine material like SF. In spite of the differences between silica fume and RHA, this latter material is considered a good replacement for silica fume. Combinations of silica fume and RHA were found to result in even higher strength values, beyond 200 MPa, than mixtures where either only silica fume or RHA were used as reactive filler (Tuan, 2011). An unexpected positive effect of the use of RHA in UHPC is the reduced autogenous shrinkage of these mixtures. The performance of RHA in UHPC mixtures will be discussed in this paper, with emphasis on the effect of RHA on autogenous shrinkage of this material.

2 Experimental study

2.1 Materials

The materials used in this study were silica sand with a mean particle size of 225 µm, Portland cement (CEM I 52.5N) with a Blaine specific surface area of 4500 cm^2/g, condensed silica fume, rice husk ash, 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 µm. The specific surface area of SF determined by the nitrogen absorption method was 19.5 m^2/g. The particle size distribution and the mean particle size of materials in this study were determined by laser diffraction. Even though only fine sands are used for producing the samples, the abbreviation UHPC (Concrete) will be used for this material.

Rice husk, an agricultural waste material 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 in detail by Bui (2001). The obtained ash was ground in a vibrating ball mill for 90 min. The ash contained 88.0% amorphous SiO_2, 3.81% loss on ignition. The mean size of the RHA particles is 5.6 µm. The specific surface area of RHA, also determined by the nitrogen absorption method, was 20.6 m^2/g.

In order to study the effect of fineness of RHA on the autogenous shrinkage of UHPC in more detail, three other types of RHA were considered in this study with the mean particle sizes of 3.6 µm, 6.3 µm and 9.0 µm. These ashes were produced in a vibrating ball mill for 30 minutes and a planetary ball mill for 3 hours, respectively. The particle size distributions of these ashes are shown in Fig. 1 with RHA 3.9, RHA 5.9 and RHA 9.0, respectively, together with the particle size distributions of the silica fume (SF) and the cement (CEM I 52.5N). The particle size distributions clearly show the big difference between the fineness of SF and RHA.

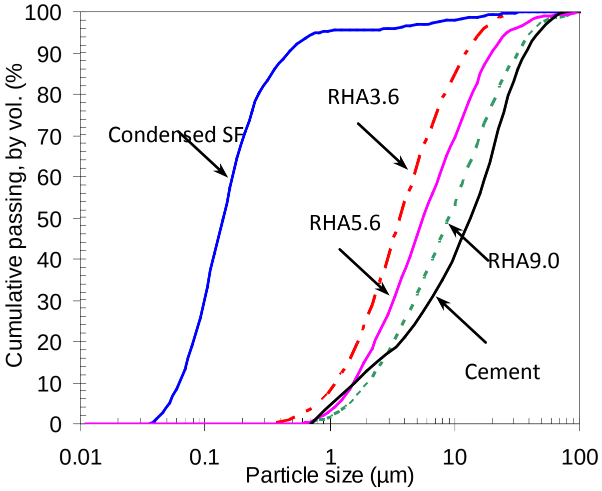

Fig. 1 Particle size distribution of materials, i.e. cement, RHA and SF, used in this study (Tuan, 2011).

2.2 UHPC mix compositions

The UHPC mix compositions are shown in Table 1. The binder consists of cement and either SF or RHA. The cement replacement percentages of the SF and RHA were 10% and 20% by weight of the cement. The amounts of superplasticizer were chosen so as to keep the workability of UHPC mixtures between 210 and 230 mm, measured by means of flow table test. Strength tests have also been performed on mixtures with a mixture of silica fume and rice husk ash. Some results will be shown in this paper. For details of the mix composition for the strength tests reference is made to Tuan (2011).

Table 1
UHPC mixtures for autogenous shrinkage measurements (after Tuan, 2011)

Mix No.	Amount of cement, [kg/m^3]	w/b ratio (by weight)	Sand/binder ratio (by weight)	RHA (% by weight)	SF (% by weight)	The mean particle size of RHA [µm]
REF	1140	0.18	1	0	0	
RHA10(5.6)	1010	0.18	1	10	0	5.6
SF10	1010	0.18	1	0	10	
RHA20(3.6)	885	0.18	1	20	0	3.6
RHA20(5.6)	885	0.18	1	20	0	5.6
RHA20(6.3)	885	0.18	1	20	0	6.3
RHA20(9.0)	885	0.18	1	20	0	9.0
SF20	885	0.18	1	0	20	

2.3 Compressive strength test methods

The mixtures were prepared in a 20-litre Hobart mixer. The volume of each batch was 3.5 litres. The compressive strength of the pastes was measured on 40×40×40 mm cubes. After casting the mixtures were vibrated for 1 minute using a vibrating table with a frequency of 2500 cycles/minute.

2.4 Autogenous shrinkage measurements

The autogenous shrinkage of UHPC mixtures was measured according to the ASTM C1698 standard (ASTM Standard 2009), in which three sealed corrugated moulds of 440 mm Ø28.5 mm were used for each mixture. The apparatus used to measure the autogenous shrinkage is shown in Fig.2. After filling of the tubes with the fresh mixture, length measurements started at the time of final set of the mixture. All samples and the dilatometer were kept in a thermostatically controlled room during the whole test. The ambient temperature was maintained at (23±1)^{o}C.

Fig. 2 Dilatometer bench with accessories used to determine autogenous shrinkage (ASTM Standard)

3 Test results

3.1 Compressive strength

Fig. 3 shows the results of compressive strength of UHPC after 3, 7, 28 and 91 days for mixtures made with 10% SF (by weight of total binder) versus the RHA(5.6) replacement percentage. The highest strength values were obtained for mixtures made with a combination of 10% SF and 10% RHA(5.6). With this mixture strength values were reached of 185 MPa and 205 MPa at 28 days and 91 days, respectively. This suggests a positive synergy effect when a mixture of these two different powders is added to the mixture.

Strength data presented in Fig. 4 refer to the reference mixture (100% Portland cement) and mixtures with 20% replacement of the cement by either SF or RHA (mean particle size of ashes 3.6, 5.6, 6.3 and 9.0 μm). It is noticed that at later ages, i.e. beyond 7 days, the compressive strength of the RHA-modified samples is higher than that of the control sample. After 3 days the compressive strength of the RHA-modified samples RHA3.6 and RHA5.6 is even higher than that of the SF-modified sample. The compressive strengths of the RHA-modified samples are 175 and 185 MPa at 28 and 91 days, respectively, whereas the corresponding values for the control sample are 163 and 173 MPa. The highest strength is obtained with mixture RHA3.6, i.e. the mixture with the finest ground RHA. The strength of this mixture is substantially higher than the mixture made with 20% SF.

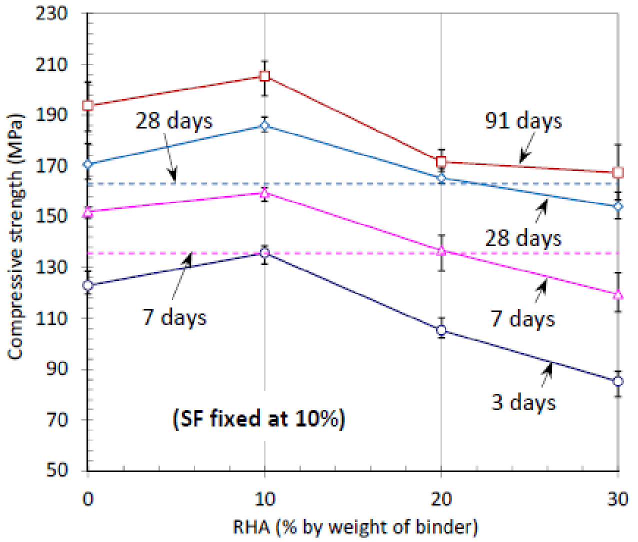

Fig. 3 Compressive strength development of UHPC samples vs. RHA(5.6) percentage. Mixtures made with SF content of 10%. w/b = 0.18 made with a mixture (Tuan, 2011).

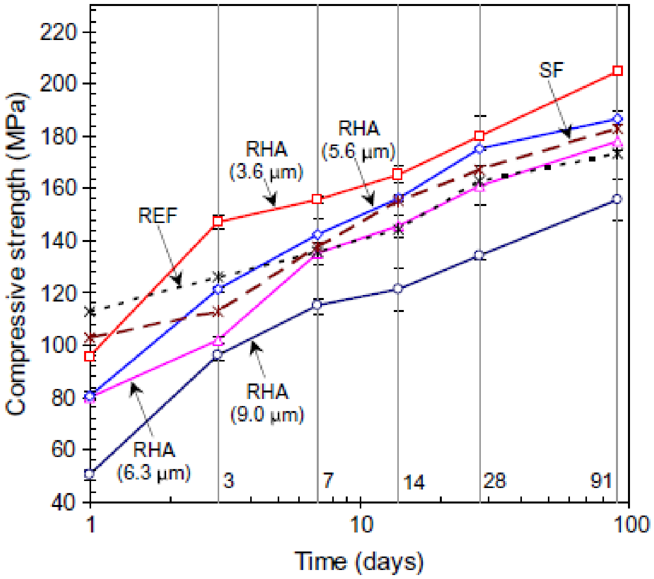

Fig. 4 Compressive strength development of UHPC. Mixture composition: Table 1 (Tuan, 2011)

3.2 Effect of RHA replacement on autogenous shrinkage of UHPC

Fig. 5 shows the development of autogenous shrinkage of UHPC with 0% (REF), 10% and 20% RHA(5.6). The figure shows that most of the autogenous shrinkage occurs in the first 12 hours after casting. There is a big influence, however, of the added RHA. After 12 hours the autogenous shrinkage of the mixture with 20% RHA(5.6) is significantly lower than that of the reference mixture. The autogenous shrinkage of the mixture with 10% RHA(5.6) is found between that of the reference

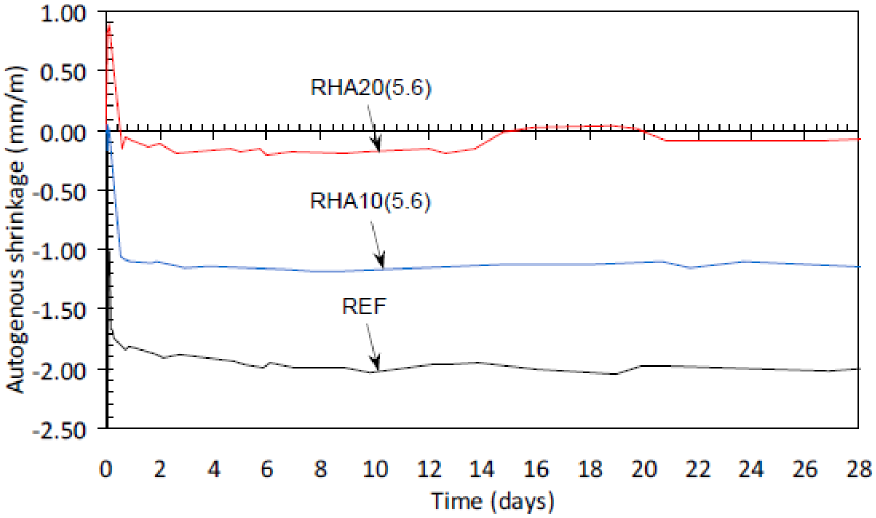

Fig. 5 Autogenous shrinkage of three UHPC-mixtures (Table 1). Reference (REF) and RHA-pastes with 10% and 20% replacement of cement by RHA with mean particle size 5.6 μm (Tuan, 2011).

mixture and mixture RHA20(5.6). After 14 days mixture RHA20(5.6) even showed a slight expansion. This tendency to expand is not observed for the reference mixture (REF) and the mixture with 10% RHA (RHA10(5.6)).

In Fig. 6 the effect of the mean particle size of the RHA is shown for mixtures with 20% replacement of cement by RHA. The autogenous shrinkage of mixtures RHA20(9.0) and RHA20(5.6) are almost identical. Similar to mixture RHA20(5.6) also mixture RHA20(9.0) exhibits a tendency to slightly expand in the period between 14 and 22 days. The autogenous shrinkage of the mixture with the fine ground ash, i.e. mixture RHA20(3.6), is found between the reference mixture and the two mixtures RHA20(5.6) and RHA20(9.0).

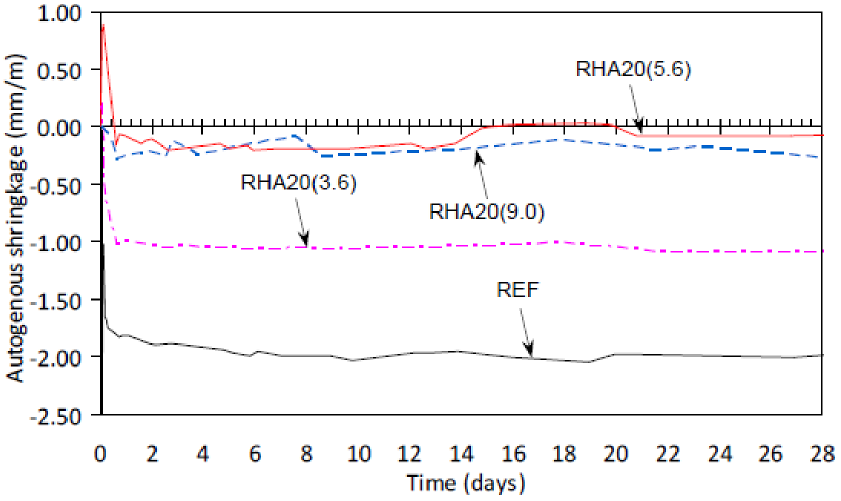

Fig. 6 Autogenous shrinkage of UHPC mixtures containing RHA with different mean particle sizes measured from the final setting time until 28 days (Tuan, 2011).

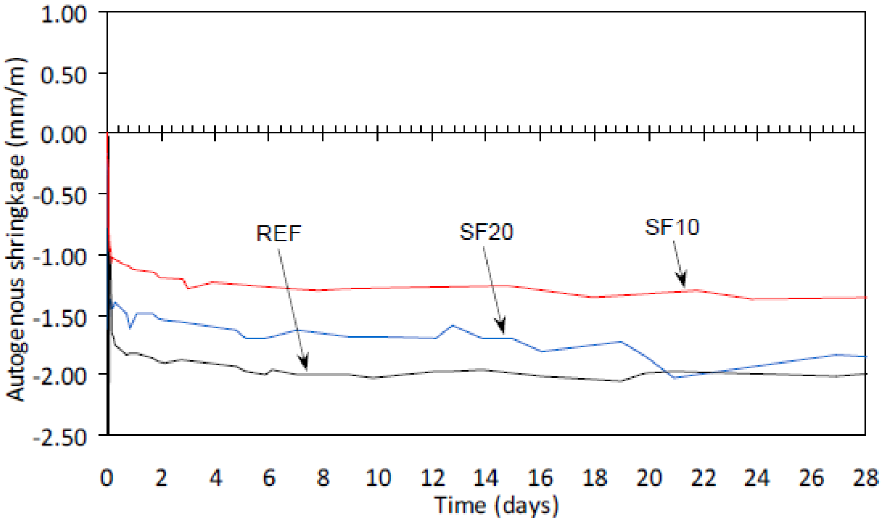

Fig. 7 Autogenous shrinkage of UHPC mixtures containing different amounts of SF measured from the final setting time until 28 days (Tuan, 2011).

3.3 Effect of SF replacement on autogenous shrinkage of UHPC

In Fig. 7 the autogenous shrinkage of mixtures with 10% and 20% SF are shown, together with the autogenous shrinkage of the reference mixture. The curves show that the effect of silica fume on autogenous shrinkage is completely different from that of RHA. The difference is largest for the mixtures with coarser RHA particles. The autogenous shrinkage of mixture SF20 is close to that of the reference mixture, whereas the mixtures with 20% RHA, i.e. RHA20(5.6) and RHA20(9.0), hardly show any net autogenous shrinkage after 12 hours (Fig. 6).

4 Discussion

4.1 Strength development

The high strength of ultra high strength cement-based materials is generally considered to be caused by improved particle packing. In case of silica fume modified mixtures, the fine silica fume particles fill up the voids between the coarser cement particles, resulting in the well-documented high strength of these materials. Particle packing, however, appears not to be the only parameter that can explain the high strength of blended cement-based materials. Fig. 8 shows the packing density of the mixtures made with 20% replacement of the cement by RHA and SF, respectively, as measured by Tuan (2011). The highest packing density was obtained with the SF-modified mixture. The highest strength, however, was found for the mixture with RHA(3.6) (see Fig. 5). The packing density of the mixture with the coarser RHA(5.6) was almost identical to that of mixture RHA(3.6), but the strength was lower than that of mixture RHA(3.6), but still higher than that of the mixture made with fine silica fume (Fig. 5). From these observations we learn that also other parameters than the packing density determines the compressive strength. One of these parameters concerns the porous microstructure of the RHA particles. Because of its porous structure, RHA has a very large specific surface area. The pores of RHA may absorb a certain amount of water. This water might be released from these pores when the relative humidity in the paste decreases with progress of the hydration process, resulting

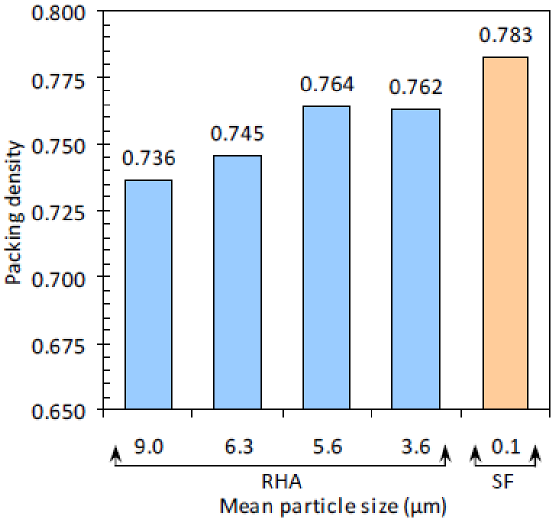

Fig. 8 Measured packing density of UHSC mixtures made with 20% replacement of the cement by SF and RHA with mean particle diameters from 3.6 to 9.0 µm (Tuan, 2011).

in an increase of the degree of hydration of the blended cement and a higher strength. This is a type of internal curing similar to that proposed by Weber et al. (1997) and Van Breugel *et al.* (1999) when using the water saturated lightweight aggregates, or proposed by Jensen and Hansen (2001; 2002) when using SAP particles for internal curing of concrete.

4.2 Autogenous shrinkage

Autogenous shrinkage is the result of self-desiccation caused by the ongoing hydration process. The lower the w/b ratio, the more susceptible the mixture is for autogenous shrinkage. Autogenous shrinkage can be reduced by the internal curing mechanisms mentioned in the previous paragraph already. It has been reported that the autogenous shrinkage of concrete mixtures, w/b ≈ 0.4, in which 25% of the dense aggregate was replaced by water saturated light weight aggregate, was reduced to almost zero (Van Breugel et al. 1999). It is suggested that such an internal curing mechanism might also explain why the autogenous shrinkage of RHA-modified mixtures is substantially reduced compared to the reference mixture and the SF-containing mixtures. RHA particles are porous and might release absorbed water once the self-desiccation process starts. The mixtures with RHA20(5.6) and RHA20(9.0) appear to be more effective in this respect than RHA20(3.6) (see Fig. 6). This may be caused by the collapse of the porous microstructure of the RHA particles during grinding of the ash to very small particles sizes. The collapse of the microstructure reduces the amount of water that can be absorbed by the RHA particles. This hypothesis is supported by measurement of the specific surface area (BET nitrogen absorption) of the RHA particles. The data are presented in table 2. The specific surface area of RHA(5.6) was found to be higher than that of the finer RHA(3.6) and also higher than that of the coarser ashes. In the range of investigated ashes mixture RHA(5.6) appears to exhibit an optimal pore structure in view of internal curing and mitigation of autogenous shrinkage.

Table 2 Properties of different types of RHA

Property	RHA(3.6)	RHA(5.6)	RHA(6.3)	RHA(9.0)
Mean particle size [µm]	3.6	5.6	6.3	9.0
Specific surface area (BET) [m^2/g]	15.0	20.6	19.7	18.3

5 Conclusions

In this paper the potential of rice husk ash (RHA) for production of ultra high performance concrete (UHPC) has been discussed. RHA, an agricultural waste product, ground at different fineness, was found to be an excellent replacement of the finer, but also more expensive silica fume. The effect of the fineness of the RHA on both the strength and autogenous shrinkage were investigated for mixtures with w/b = 0.18 and a maximum particle size of the aggregate, i.e. sand, of 225 μm. Parallel measurements on strength and autogenous shrinkage were performed on mixtures made with silica fume. The following conclusions were drawn.

- The packing density of UHPC mixtures appeared important, but not decisive for the strength of the mixtures. A comparison of mixtures in which 20% of the cement was replaced by silica fume or RHA, showed that the strength of mixtures with RHA with a mean particle size of 3.6 to 5.6 μm was higher than that of mixtures with 20% silica fume, even though the packing density of the SF-modified mixtures was higher than that of the RHA-modified mixtures. The conclusion seems justified that RHA is a reasonable and environment friendly alternative for silica fume for the production of UHPC as far as strength is concerned.
- Partial replacement of cement by RHA, by up to 20% of the weight of the cement, appeared to have a mitigating effect on autogenous shrinkage. Autogenous shrinkage measurement on RHA-modified mixtures showed that ashes with a mean particle size of 5.6 μm reduced the autogenous more that ashes with a smaller (3.6 μm) or larger (9.0 μm) mean particle size. The reduction of autogenous shrinkage is assumed to be caused by an internal curing mechanism, for which the water containing porous RHA particles are responsible. RHA particles with a mean particle size of 5.6 μm appeared to be most effective in this respect. These ashes appeared to have to highest specific surface and are obviously best prepared to absorb water that could be released during the self desiccation process of these low w/b mixtures. The ability of RHA particles to reduce the autogenous shrinkage in low w/b mixtures makes this low cost material an excellent alternative for expensive silica fume for production of ultra high performance materials.

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