Ultra High Performance Concrete Using Waste Materials for High-Rise Buildings

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Abstract: Ultra High Performance Concrete (UHPC) is usually considered to be over 150 MPa in compressive strength and over 20 MPa for flexural strength. Therefore, UHPC offers considerable potential in forward-thinking designs for thinner/larger post-tensioned slabs and smaller/longer columns in the construction of high-rise buildings. This paper presents a number of experimental results on the mechanical properties of UHPC using different types of waste material, including fly ash, ground granulated blast furnace slag, and rice husk ash. The results show the potential of using these waste materials to produce UHPC, especially in developing countries such as Vietnam where the limited availability and high cost of silica fume constrains its application in the high strength concrete industry. This therefore also has potential for contributing to the sustainable development and economic prosperity of the concrete industry and wider construction sector in Vietnam and other developing countries.

Key-words: pulverized fly ash (PFA), rice husk ash (RHA), slag, ultra high performance concrete (UHPC)

1. Introduction

Ultra High Performance Concrete (UHPC) has been developed steadily during the last two decades. This concrete is a very promising material with superior strength and excellent durability. The compressive and flexural-tensile strengths of UHPC have been proved to be over 150 MPa (possibility attaining 250 MPa) and 20 MPa respectively [1]. Meanwhile, the corresponding values of current High Strength Concrete (HSC) are around 60-100 MPa and 6-10 MPa respectively. Using UHPC rather than High Strength Concrete (HSC) for high-rise buildings has the potential to reduce the cross-sections of structural components and hence the total weight of buildings dramatically. This also means that high-rise buildings will have more freedom in terms of increasing their height when using UHPC for the main structures, as well as potentially being more sustainable due to using less material overall.

Concrete can incorporate by-product or waste materials such as pulverised fly ash (PFA), ground granulated blast furnace slag (GGBS), silica fume (SF) and rice husk ash (RHA) for cement replacement as part of its standard manufacturing process. This actually reduces the CO_2 footprint of Portland cement and the by-products do not need to be land-filled. Concrete can utilize high volumes of these supplementary cementitious materials to further contribute to the requirements of sustainable construction, especially for producing UHPC which contains very high amount of cement, ranging from 900 to 1100 kg/m^3 [2, 3]. Moreover, in UHPC, silica fume (SF) is an essential component (with an extreme fineness and high amorphous silica) plays a very important role with physical (filler, lubrication) and pozzolanic effects to increase the strength. The typical SF to cement ratio applied in UHPC is 0.25 to achieve these effects [2]. As available resources of SF are limited and SF is costly, searching for the substitution by other materials with similar functions, especially in developing countries such as Vietnam, is very necessary.

The objective of this paper is to present the possibility of using different types of waste materials, i.e. PFA, GGBS, and RHA to produce UHPC for high-rise buildings. The data was gathered from research carried out at the National University of Civil Engineering, Vietnam; Delft University of Technology, Netherlands; and The University of Liverpool, UK.

2. Materials and methods

The materials and research methods used in these studies are separated into two catalogues as shown in Table 1. The details of each catalogue containing the mix proportions of UHPC were described elsewhere [4, 6].

Table 1. Materials and methods used in the study

	Catalogue 1	**Catalogue 2**
Type of Portland cement	CEM II/A-V 42.5 N	CEM I 52.5 N
The cementitious materials	SF, GGBS, PFA	SF, RHA
Silica sand, an average particle size (μm)	270	225
Superplasticizer	Polycarboxylate based	Polycarboxylate based
Method for measure workability	The flow table*	The flow table*
Sample size and shape for compression test	50 and 100 mm cubes	40 mm cubes
Curing condition	20^{o}C and 90^{o}C	20^{o}C

* BS 4551: Part 1: 1998 [7]

3. Results and discussion

The experimental results are separated into two parts corresponding to the two catalogues shown in Table 1. The first part mainly presents the result of UHPC incorporating SF, GGBS and PFA. The details of these results were presented in [4, 5] by Le Trung Thanh et al. The second part focuses on the effect of RHA in combination with and without SF on producing UHPC. The details of these results could be found in [6, 9] by Nguyen Van Tuan et al.

3.1. UHPC incorporating SF, GGBFS and PFA

Figure 1 shows the effect of the amount of SF on the compressive strength of UHPC at the age of 7 and 28 days. It can be seen that the highest compressive strength of UHPC was achieved with 20% cement replacement by SF at either 20^{o}C or 90^{o}C curing. However, the increase of compressive strength of UHPC is relatively small when cement was replaced by SF from 10 to 20% at 28 days. Regarding of the cost of SF, about three times compared to that of Portland cement, the percentage of cement replacement by SF of 10% is adopted as 'optimum' in this case. The binder herein is the sum of cement and SF with and without GGBS or PFA).

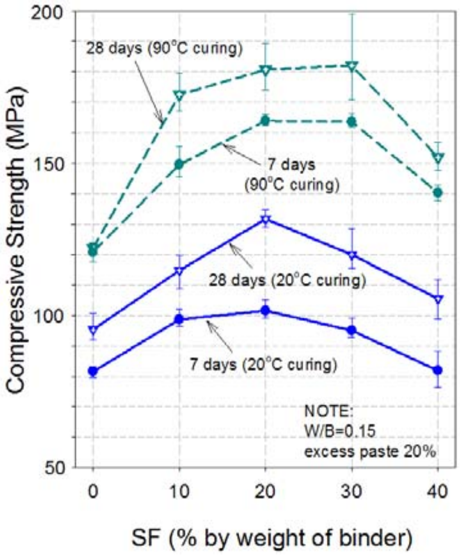

Figure 1. Compressive strength of UHPC samples vs. % SF (by weight of binder), w/b ratio = 0.15, 28 days, at 20°C and 90°C curing

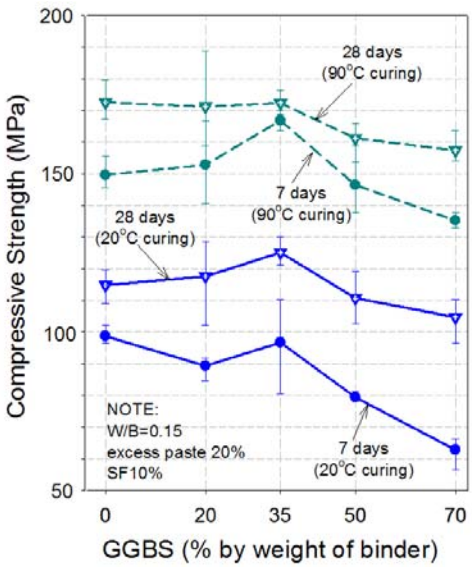

Figure 2. Compressive strength of UHPC samples vs. % GGBS (by weight of binder), w/b ratio = 0.15, 28 days, at 20°C and 90°C curing,, SF replacement fixed at 10%

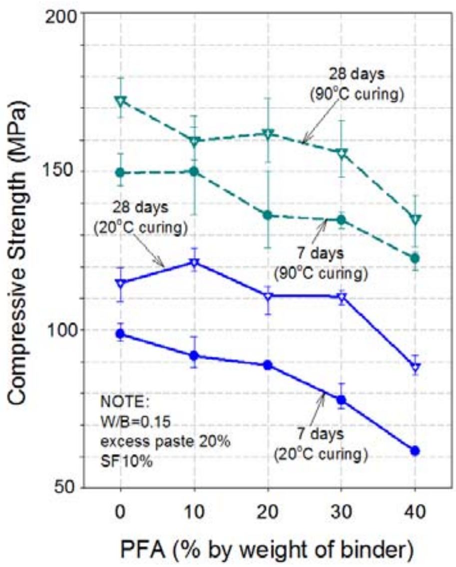

Figure 3. Compressive strength of UHPC samples vs. % PFA (by weight of binder), w/b ratio = 0.15, 28 days, at 20°C and 90°C curing, SF replacement fixed at 10%

Therefore, the SF replacement was fixed at 10% to further investigate the effect of GGBS and PFA on the compressive strength of UHPC. These results are shown in the Figure 2 and Figure 3. It is interesting that partial replacement of cement by GGBS and PFA up to 50% and 30%, respectively, did not significantly decrease the compressive strength of UHPC cured at either 20°C or 90°C.

3.2. UHPC incorporating RHA

In this study, RHA, an agricultural waste material from Vietnam, was burnt in a drum incinerator. Details of the oven and rice husk combustion process were described elsewhere [8]. The obtained ash was ground in a vibration ball mill for 90 minutes. The ash contains 87.96% amorphous SiO_2, 3.81% loss on ignition and its mean particle size ($d_{RHAmean}$) is 5.6 µm.

The effect of RHA in comparison with SF on compressive strength of UHPC is shown in Figure 4. It can be seen that the compressive strength of UHPC was improved significantly with 10% SF or 20% RHA (compared to the control sample with 0% SF or 0% RHA). For samples containing SF, the highest compressive strength of UHPC was achieved with 10% SF replacement of cement. Higher replacement levels, especially beyond 20%, led to reduction in compressive strength. The use of RHA as a partial replacement of cement revealed the different behavior of compressive strength development. At the early ages, i.e. 3 to 7 days, the compressive strength of UHPC using 10% RHA was higher than 20% RHA, but was lower in the late ages of 28 and 91 days, see Figure 4. Based on this result, the cement replacement by SF was also fixed at 10% to further investigate the possibility of using RHA to produce UHPC. The result is shown in Figure 5.

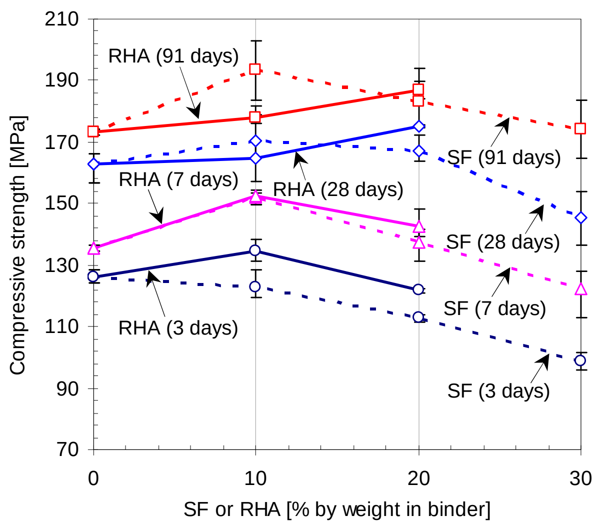

Figure 4. Compressive strength vs. % RHA (solid line) and % SF (dotted line) at 3, 7, 28, and 91 days; w/b ratio = 0.18; the mean RHA particle size of 5.6 µm, at 20°C curing

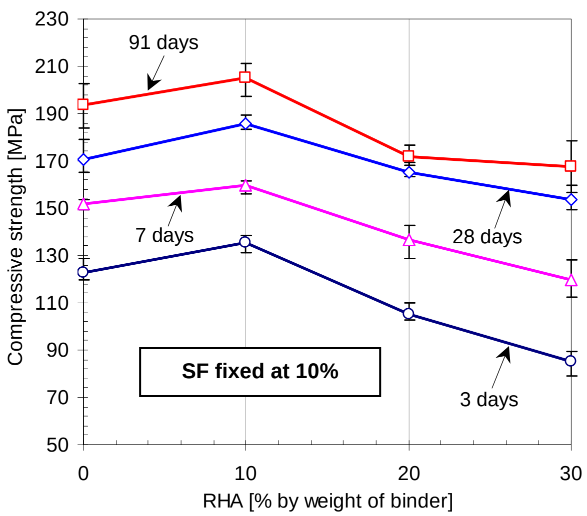

Figure 5. Compressive strength vs. % RHA at 3, 7, 28 and 91 days; w/b ratio = 0.18; the mean RHA particle size of 5.6 µm, at 20°C curing, SF replacement fixed at 10%

It is very interesting to note that UHPC using blend of 10% RHA and 10% SF gives the highest compressive strength at all ages. It should be noted that the maximum amount of cement replacement by the blend of RHA and SF to produce UHPC can increase 40% under the normal curing condition. From this result, a further investigation of using the combination of 10% RHA and 10% SF in producing UHPC was performed [9]. In this study, the type of cement, CEM I 52.5 N, is replaced by slag cement, CEM III/B 42.5 N which contained 69% slag by weight. Figure 6 shows the development of compressive strength with time. It can be seen that the compressive strength of 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 was not significantly different from that of the sample using cement CEM I 52.5 N.

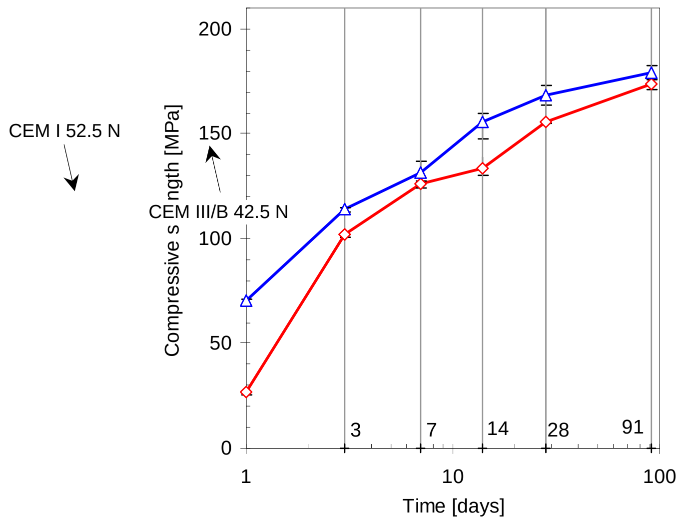

Figure 6. Compressive strength of UHPC samples vs. time, w/b ratio = 0.18, the mean RHA particle size of 5.6 μm, at 20°C curing

This result exhibited the benefit of using the combination of RHA and SF to produce UHPC. The percentage of the combination of RHA and SF in the mixes was 20%. This means that the total cement replacement percentage in UHPC made by cement CEM III/B 42.5 N was about 75% by weight.

Ordinary Portland cement (OPC) is acknowledged as the major construction material throughout the world. The production rate is approximately 2.1 billion tones per year, and is expected to grow exponentially to about 3.5 billion tones per year by 2015 [**10**]. According to the Ministry of Construction, Vietnam currently possesses 105 cement production plants with a combined annual capacity of 61 million tones. Most of the increase in cement demand will be met by the use of supplementary cementitious materials, in order to reduce green gas emissions [**11**]. Industrial wastes, such as GGBS, PFA and SF are being used as supplementary cement replacement materials and, recently, agricultural wastes are also being used as pozzolanic materials for concretes, such as RHA [8, 12].

In Vietnam, the capacity of total industry relevant by-products is about 3 million tones/year, in which PFA and slag is about 0.7 and 1 million tones/year, respectively. In comparison, the paddy production of Vietnam is 39 million tones in 2009 [13]. Rice husks are by-products of rice paddy milling industries and each ton of dried rice paddy produces about 20% of waste husks [8], giving an annual total national production of 7.8 million tones of waste RHA. Assuming an ash to husk ratio of 20% [8], the total potential ash production could be as high as 1.5 million tones per year. Therefore RHA is also a potential material for producing UHPC.

4. Conclusions

This study has shown the potential for using some waste materials to produce UHPC for high-rise buildings. The following conclusions can be drawn:

- The waste materials such as SF, GGBS, PFA, RHA can be considered as a usable supplementary cementitious material using for producing UHPC.

- 10% partial cement replacement with SF was found to be sufficient for obtaining high compressive strengths. In combination with 10% SF, up to 50% GGBS or 30% PFA or 40% RHA can be used as partial cement replacements without significantly affecting the compressive strength of UHPC.

- The blend of 10% RHA and 10% SF can be used to produce UHPC even with slag cement, CEM III/B 42.5 N, containing 69% slag. The percentage of Portland cement in this case was only 25% by weight of total binder.

The use of these waste materials in the concrete industry is also one of the solutions to help reduce the environmental pollution caused by the production and manufacture of cement and concrete. Additionally, the use of RHA replacing SF in production of UHPC is especially applicable in developing countries, e.g. Vietnam, where the limited availability and the high cost currently constrain the application of SF and hence the use of UHPC. This study therefore will help contribute to the sustainable development and economic prosperity of the concrete industry in Vietnam and other developing countries.

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