Effect of the heat curing on strength development of ultra-high performance fiber reinforced concrete (UHPFRC) containing dune sand and ground brick waste

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Abstract. This work aims to investigate the strength development of ultra-high performance fiber reinforced concrete (UHPFRC) containing ground dune sand (GDS) and ground brick waste (GWB) as a substitutions of cement and dune sand (DS) as an aggregate. The variables are the nature of addition (GDS and GWB) in the binder and the heat curing at different temperatures (20°C and 60°C) at 7 days of curing. Two temperatures 20°C and 60 °C were applied to samples with intermediate levels for 8 hours in total. In this study, two types of cements (CEMI and CEMII) were used to prepare UHPFRC. The GWB was replaced by GDS at levels of 10, 20 and 30% by weight. The results show that the obtained concretes develop a high mechanical performance with a suitable heat treatment according to the cement type and the used fiber. The compressive strength at 7 days of UHPFRC has increased with heat curing (at 60 °C) compared to that obtained at 28 days and measured at 20 °C. Results show also that values of compressive strength of concrete containing DS are close to those obtained by the control concrete. This study has showed that the dune sand can be used in UHPRC, and that the substitution of the GWB by GDS can provide concretes with acceptable mechanical performance.

Key words: Ultra-high performance fiber reinforced concrete, dune sand, ground dune sand, ground brick waste, compressive strength, heat curing.

1. Introduction

Recent advances in concrete technology have enabled the development of new concretes named Ultra High Performance Concrete (UHPC), which have very high compression strength and a good rigidity (Richard, 1994; Rossi, 1996; Vernet, 1998). In practice, the formulation of such concretes requires adequate components and well controlled composition parameters. Fundamental studies on the mechanical properties and behavior analysis of UHPC elements were achieved gradually over the last decade by some researches (Richard, 1994; Aitcin, 1996; Dubey, 1998; Vernet, 1998). Most of these studies have also studied the use of cementitious materials in UHPC in order to obtain concrete with high mechanical performance. Dune sand (DS) can be used as an aggregate and ground dune sand (GDS) can be used as a cementitious material in the new generation of concretes. A very detailed study was reported by Tafraoui et *al*. (2006; 2009) and Zaitri et *al.* (2014) on the valuation of DS and GDS in the formulation of high performance concrete. The results showed that DS can be considered as an aggregate and GDS can be considered as a cementitious material for the formulation of high performance concrete.

The present work constitutes an experimental study on the formulation and physic-mechanical characterization of ultra-high performance fiber reinforced concretes (UHPFRC). DS is used both as an aggregate for concrete and as mineral addition (i.e. GDS). A ground brick waste (GBW) and a polypropylene fiber were also used in this study. The DS dosage remains constant in all mixtures, while GDS was used as a partial substitution of GWB with different GDS/GWB ratios (0, 10, 20 and 30%). Also, the same variants of UHPFRC, were developed based on two cement types (CEM I and CEM II) to see the DS effect on the physic-mechanical properties of UHPFRC, in the presence of these two types of cement.

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2. Experimental study

2.1. Materials

Two types of cements (CEM I 52.5 and CEM II 42.5) were used in this work. Also, GWB and GDS were used as cementitious materials. Table 1 showed the characteristics of these cementitious materials and cements.

DS (0-2mm) was also used as a fine aggregate in all mixtures at fixed dosage. Figure 1 shows the particle size distribution of DS.

Polypropylene fibers (with a 12 mm long and a diameter of 0.18 mm) were used.

Table 1. Characteristics of cementitious binder.

Compounds	Cement % (by weight)		GDS % (by weight)	GWB % (by weight)
	CEMI	CEMII		
Chemical analysis				
SiO_2	21.46	17.96	94.40	52.22
Al_2O_3	04.55	4.50	2.23	10.49
Fe_2O_3	04.08	2.98	0.33	02.54
CaO	65.01	61.03	0.68	12.83
MgO	3.42	1.98	0.08	13.24
SO_3	2.08	2.08	0.17	0.52
$K_2O + Na_2O$	1.21	0.91	1.49	1.24
Loss of ignition	-	-	0.82	2.52
Mineralogical analysis				
C_3S	61.39	59.02	-	-
C_2S	17.01	19.36	-	-
C_3A	05.15	06.45	-	-
C_4AF	12.04	12.26	-	-
Physical properties				
Specific gravity (g/cm^3)	3.10	3.02	2.63	2.42
Specific surface (m^2/kg)	380	390	800	780

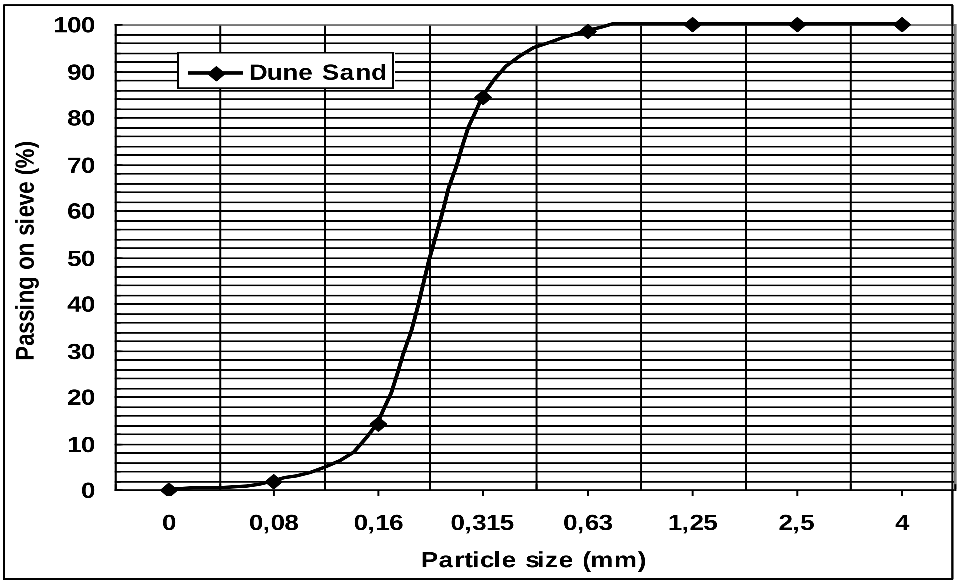


Fig 1. The Particle size distribution of dune sand.

2.2. Mix design and proportioning

The UHPFRC were established according to the typical formulation of UHPC proposed by CimBéton (2013). Most formulations of UHPFRC are currently designed experimentally. To this end, a process was established before the UHPFRC composition, verification of the final composition of the concrete by the mini-cone test. The water/binder ratio used was fixed (W/B = 0.19) and the mixing process was kept constant for all mixtures. Table 2 shows the mixes details of control concrete and three UHPFRC.

Table 2. Details of concrete mixtures.

	Cement* (kg)	DS (kg)	Mineral additions (kg)		Fiber (Kg)	SP(Kg) Ext. Sec	Water (l)	W/B
			GDS	GWB				
CC	710	1020	203	215	1	12	220	0.19
C10%	710	1020	223,3	194,7	1	12	220	0.19
C20%	710	1020	243.6	174.4	1	12	220	0.19
C30%	710	1020	263.9	154.1	1	12	220	0.19

* Two types of cement were used: CEMI and CEMII.
Notations: CC: Control Concrete; C10%, C20% and C30% are respectively UHPFRC with 10%, 20% and 30% of GDS by partial substitution of GWB.

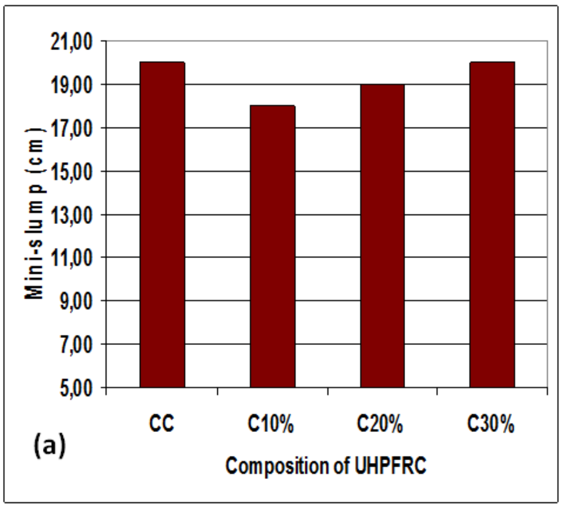
2.3. Test method

To conduct this work, prismatic samples (40x40x160 mm³) were manufactured for each mixture. One day after casting, samples were stored in water under 21±1°C. The other specimens of UHPFRC were subjected to a specific heat curing in water (60°C for 8 hours) at 7 days and then test specimens were stored yet in water for 28 days (Kjellsen, 1996; Edrogdu, 1998). The various tests and measurements were carried out in order to study the mechanical properties (compressive strength).

3. Results and discussions

3.1. Fluidity of UHPFRC

Variation of fluidity, for studied concretes, as function the different content of GDS is represented in Figure 2. It was observed according these results that all concretes show a spread diameter varying between 18 and 20 cm. However, a slight decrease in the fluidity of C10% was remarked (with CEMI see figure 2(a)). Although, the decrease of fluidity was observed with C20% in case of CEMII (see figure 2(b)). Figure 3 shows examples of UHPFRC fluidity test by mini-cone.



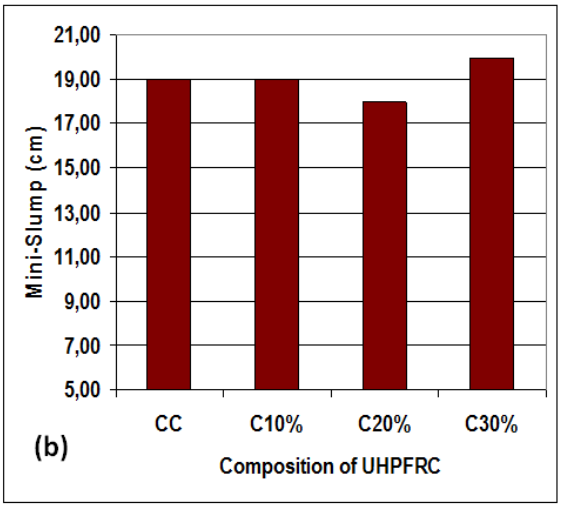


Fig 2. Fluidity of studied UHPFRC based on: (a) CEM I (b) CEMII.

Fig 3. Fluidity test by mini-cone.

3.2. Bulk density

Figure 4 give the bulk density of UHPFRC as a function the GDS content, after 28 days of water maturation of the samples. For all mixtures, the bulk density was slightly increased with the replacement level of GWB by GDS; this can be explained by the fact that GDS is denser than GWB (see Table 1).

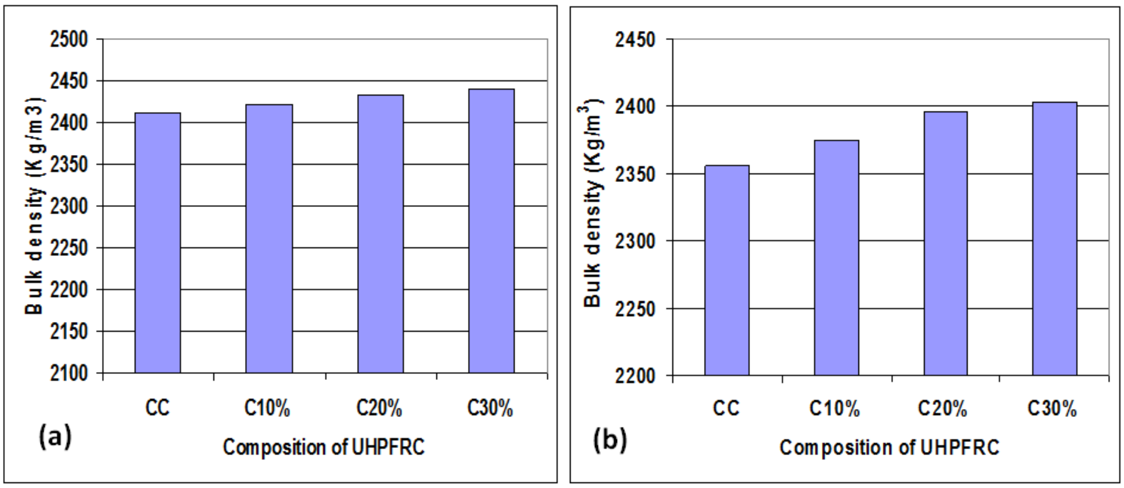


Fig 4. Bulk density of studied UHPFRC based on: (a) CEM I (b) CEMII.

3.4. Compressive Strength

The compressive strength of studied UHPFRC based on CEMI and CEMII are presented respectively in Figure 5(a) and Figure 5(b). Results show that the compressive strength is remarkably increased with the increase of GDW at all curing times. It can be also seen that the highest compressive strengths were recorded for UHPFRC concrete based on CEMI (the highest value was 160 MPa for C30% composition).

An attempt was made to improve the compressive strength of UHPFRC prepared by the heat treatment, mentioned above in paragraph (curing specimens at 60°C for 8 hours). The results are shown in Figure 5. According to these results, it is remarkable that the compressive strength is significantly enhanced with heat treatment for all concrete. This is explained by the beneficial effect of the temperature, which accelerates the cement hydration reactions (Edrogdu, 1998; Kjellsen, 1996; Tafraoui, 2009). The latter can generate the formation of C-S-H which increases the compressive strength of concrete.

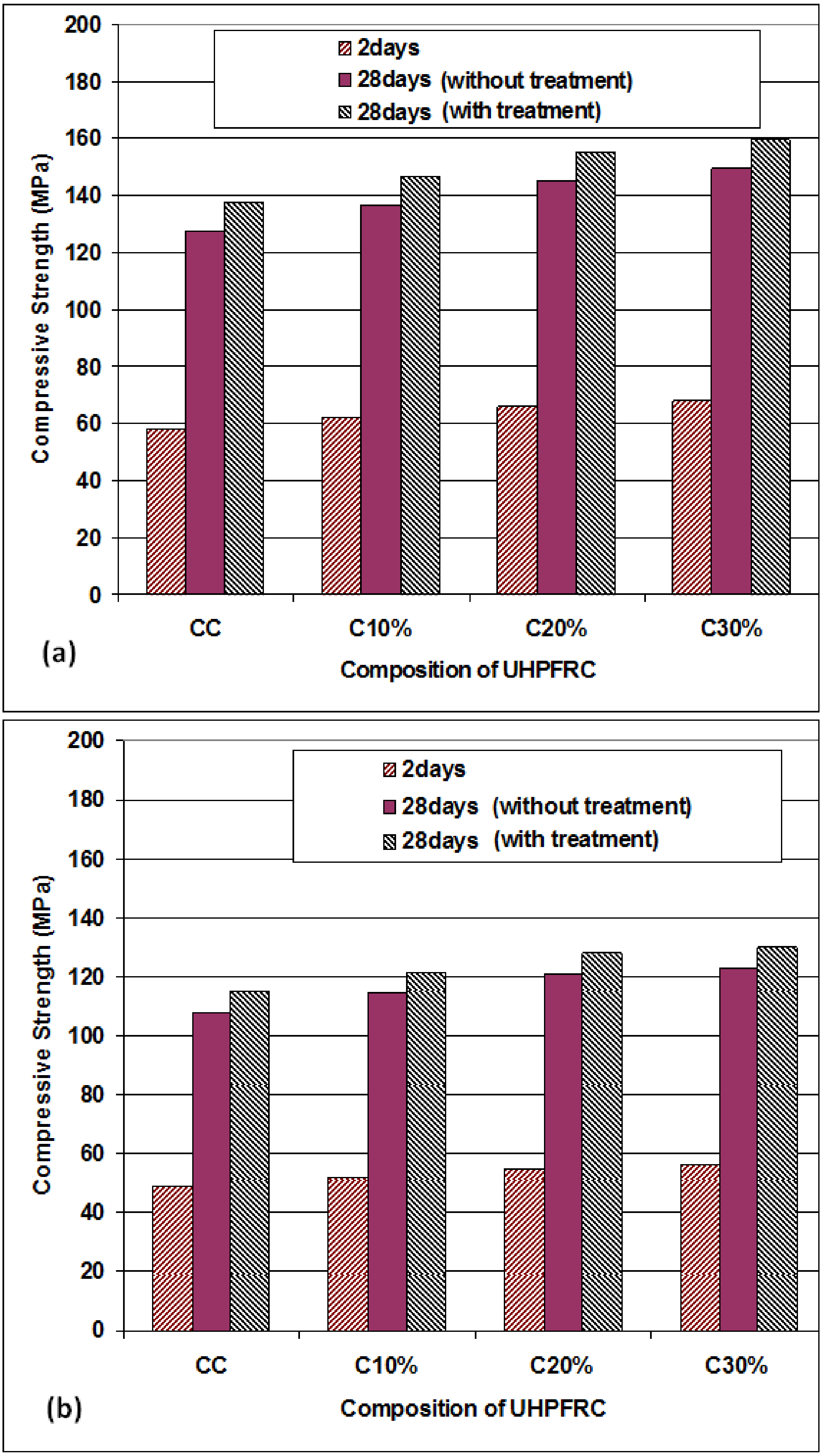


Fig 5. The compressive strength variation of concrete as function on the dune sand content; (a) With CEMI (b) With CEMII.

3.5. Microstructural study

A microstructural study by Scanning Electron Microscopy (SEM) of the interface fiber-concrete was conducted to analyze the properties of the interfacial zone of these two materials. In Figure 6 the fibres – concrete interface in a specimen containing 20% of GDS (28 days of hydration) is shown. It can be observed from this figure, that the interfacial zone is more dense with low cracks and with a relatively good adhesion between the polypropylene fiber and cement paste.
Also, the DS fine aggregates have been observed in the cementitious matrix. According to the images in Figure 6, it is clear that DS can be used as an aggregate because the adherence of the latter is very strong to the cementitious matrix. These images show that also GDS can be used as a binder because it has given a new product of C-S-H. It should be noted that some studies have shown that GDS can have a pozzolanic reactivity. (Tafraoui, 2006; Bédérina, 2000; Azzouz, 2008).

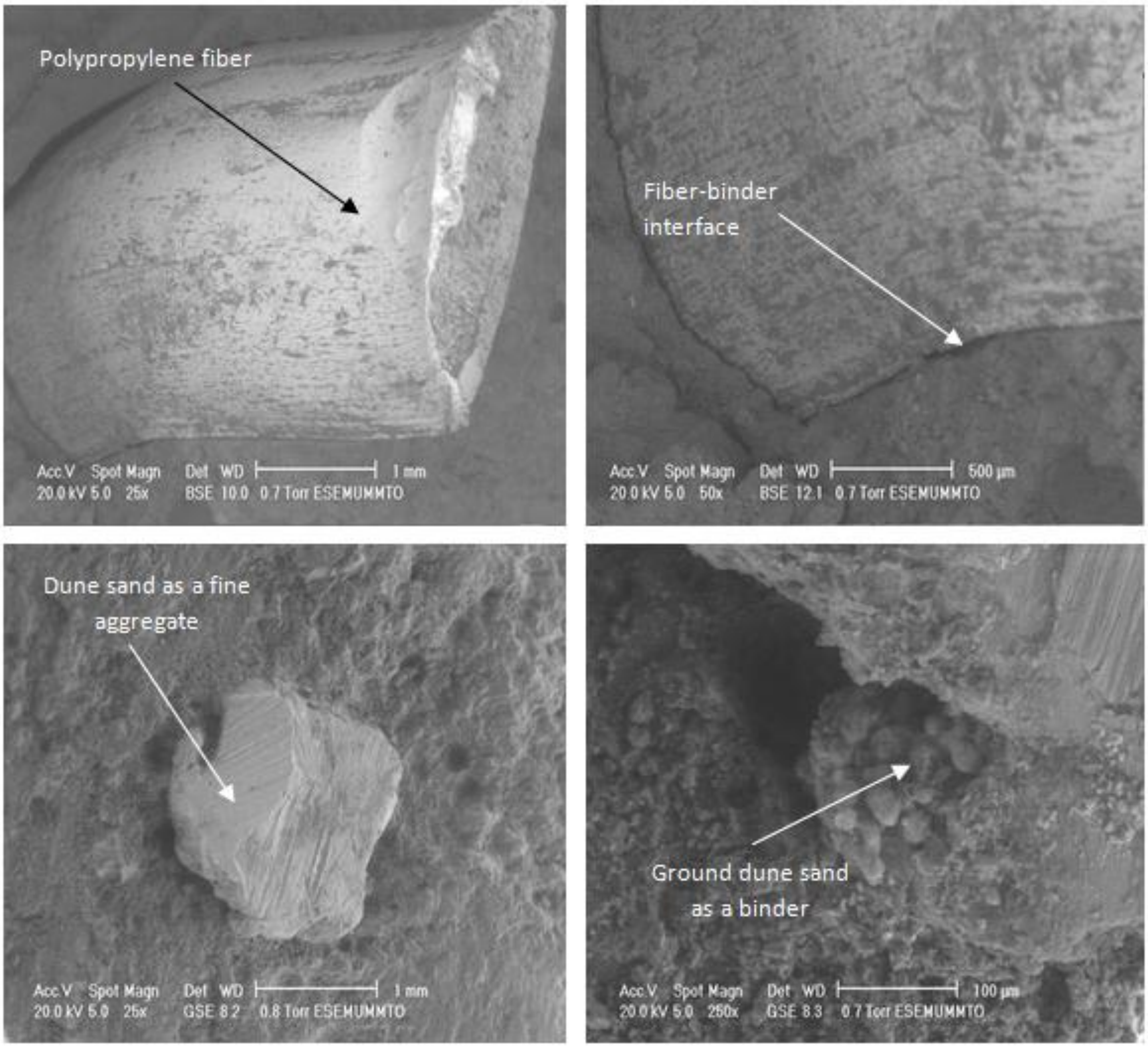


Fig 6. SEM analysis of the polypropylene fiber-binder interface.

4. Conclusions

This study has presented the use of dune sand (DS) as fine aggregate and ground dune sand (GDS) as mineral addition in UHPFRC concrete. The results which could be as follows:

- The results of the fluidity tests by mini-cone were showed that all concrete studied have a same fluidity that varies between 18 and 20 cm in diameter, which corresponds to a UHPFRC fresh requirements;
- All UHPFRC studied have the same density regardless of the replacement rate of GWB by GDS;

- By using CEMI cement type, the largest value of compressive strength of concrete is recorded (around 160 MPa for a GDS replacement ratio of 30%);
- The compressive strength is enhanced in the presence of temperature for all concrete produced. This proves the beneficial effect of the temperature, which accelerates the cement hydration reactions. The effect of temperature is remarkable enough for UHPFRC based on cement CEMI compared to concrete based on CEMII.

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