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RESEARCH ARTICLE

Reuse of Refractory Brick Wastes (RBW) as a Supplementary Cementitious Material in a Concrete

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Abstract
The main purpose of this study is to evaluate the reuse of refractory brick wastes (RWB) as a supplementary cementitious materials (by a total replacement of silica fume) to produce a new concretes; namely a high performance fiber-reinforced concrete (HPFRC). This work presents an experimental study on the formulation and physico-mechanical characterization of high performance fiber reinforced concretes based on three types of refractory brick wastes. These were recovered from the float glass industry (Mediterranean Float Glass) after their use in the oven basin (i.e. d. they are considered waste unit). Three compositions of concrete (HPFRC) were established based on three types of refractory brick wastes (finely crushed), with the dosage of each type of bricks is kept constant and similar that dosage of silica fume used for the control concrete. While all the other components and the water/binder ratio are maintained constant with the same quantity of the superplasticizer. The performance of HPFRC, were evaluated by determining the essential characteristics of fresh and hardened concrete. The results obtained showed that refractory bricks finely ground have the potential to be used as cementitious material or additions for concrete manufacture.

Keywords
refractory brick wastes, concrete, fluidity, compressive strength, tensile strength

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1 Introduction

Industrial wastes increasingly have found their place as supplementary cementitious materials in manufacturing of concretes or cement mortars. Among these wastes, the silica fume, granulated blast furnace slag, fly ash ... etc [1-3]. These wastes can be incorporated into the concrete as mineral additions or fine aggregate (sand), in order to improve some properties in the fresh state such as fluidity or hardened such as the durability of concrete material. Studies on the concrete containing ceramic wastes or firebricks are restricted. These studies have suggested making more extensive research to assess the performance of concrete containing this type of waste (particularly the firebrick wastes). On the other hand the production of one ton of cement generates 0.55 tonnes of CO_2 and requires an additional 0.39 tonnes of CO2 in fuel emissions, representing a total of 0.94 tonnes of CO_2 [4]. Therefore, the cement replacement in concrete by ceramic wastes finely ground is a huge energy savings and provides significant environmental benefits. In addition, it will also have a major effect on reducing manufacturing costs of concrete, since the cost of cement represents over 45 % of the cost of the concrete material. Several authors have already confirmed that powders of ceramic wastes have a pozzolanic reactivity [5-7]. However, research conducted to date are few and do not assess the performance of concrete durability which it is a key issue. The same could be said about investigations into the use of ceramic aggregates in concrete [8, 9].

However, the technological progress of the concretes has enabled the development of new concretes so called Ultra-High Performance Fiber Reinforced Concretes (UHPC) which exhibit compressive strengths and very high stiffness [10, 11]. In practice, the formulation of these concretes requires adequate components and composition parameters are well controlled such as the W /C ratio, the binder mixture (cement and mineral additions), etc. This latter must be higher with minimum of water (W/C lower) in order to achieve the best mechanical performances. For this reason, researchers continue to find others additions for to substitute totally the silica fume in the UHPC formulation to make it less expensive material. In practice, the formulation of these concretes requires adequate components and composition parameters are well controlled. Fundamental studies on the mechanical properties and behavior analysis of UHPC elements were achieved gradually over the last decade by some research [10-14]. Also, studies have been conducted on the use of materials cementitious in UHPC in order to obtain concretes with high mechanical performances. The dune sand is one of materials cementitious known by the characteristics that allow its use in the new generation of concretes. A very detailed study was made by Tafraoui et al. on the valuation of the sand dune in the formulation of HPC [15]. The results showed that dune sand can have a materials cementitious character for the formulation of concrete

To this purpose, the aim of this study is to evaluate potential of refractory brick wastes as a supplementary cementitious material (by total substitution of silica fume) to produce an ultra high performance concrete (UHPC). This paper presents an experimental study on the formulation and physico-mechanical characterization of ultra high performance fiber reinforced concretes based on three types of waste finely crushed firebrick. Three compositions of concrete (UHPC) were developed based on three types of waste refractory bricks (finely ground), the dosage of each type of brick is kept constant with the same dosage of silica fume used for the control concrete. While all other constituents and the water / binder ratio are maintained constant with the same quantity of the superplasticizer. The performances of UHPC were evaluated by determining the essential features fresh and hardened concrete.

2 Experimental study

2.1 Materials used

Cementitious binder: A Portland cement (CEM I 52.5) was used in this work and it is conformed to ENV norm. Also, the silica fume (SF) and the dune sand finely ground (DS), were used as materials cementitious in control concrete. The Table 1 showed the characteristics of the cementitious binder. It was noted that the dune sand (FDS) is also used as a fine aggregate (as a fine quartz sand). Refractory bricks (three types of bricks) were recovered from the MFG unit (Mediterranean Float Glass-Algeria) after their uses in the oven basin (i.e. they are considered as wastes of the unit). Then they suffered cementitious additions preparation processes, namely crushing, grinding and screening. Then, the finely milled powders were characterized before being used in the concrete composition. Refractory bricks (see Fig. 1) used in this work are; Firebrick based Alumina (BRAL); Firebrick based magnesium (BRMg); Firebrick based Silica-Zirconium (BRZr); Fig. 2 shows the particle size distribution of the firebricks used.

Fine quartz sand (FDS): the dune sand (0-2mm) is also used as a fin aggregate in all concrete mixtures at fixed dosage. The grain-size distribution of used dune sand is given is Fig. 3.

Fibres (PF): the fibres are used in this study. Polypropylene fibres have a 12 mm long with a diameter of 0.18 mm.

Superplasticizer (SP): the superplasticizer used in this study is a polycarboxylate type used currently in new concrete formulation.

Fig. 1 Refractory brick wastes used

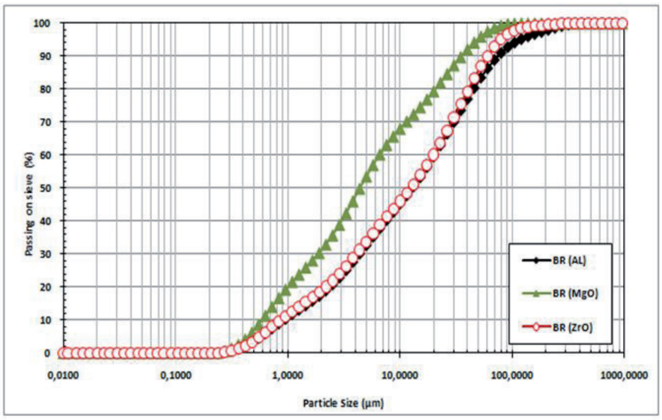

Fig. 2 Particle size distribution of the refractory brick wastes used

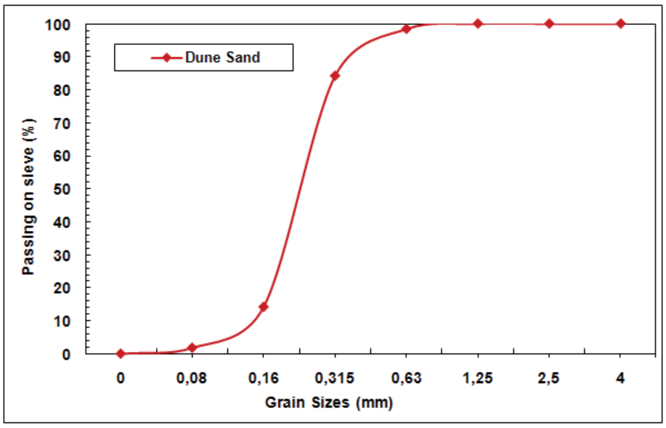

Fig. 3 The grain-size distribution of used dune sand

The figure shows the particle size distribution of three types of refractory bricks (finely ground) used in this work. From the results obtained, it is remarkable that the three types of brick (BR (AL), BR (Mg) and BR (Zr)) have the same distributions as well with the same grain diameters. This can be confirmed by the fineness obtained by these bricks after grinding (SSB; see Table 2).

The chemical composition of refractory bricks used in this work, is given in Table 2. It is remarkable that the oxide content is different in each brick. Indeed, the alumina-based brick containing more than 40 % alumina and the magnesia brick oxide contains more than 45 % MgO. By cons, brick Zirconium contains not only Zirconia (40 %) but also silica (about 12 %), but this type of brick must have a% Zr over 30 %.

Table 1 Characteristics of cementitious binders

Compounds	Cement % (by wt)	FDS % (by wt)
SiO_2	21.48	94.40
Al_2O_3	04.53	2.23
Fe_2O_3	04.08	0.33
CaO	65.01	0.68
MgO	3.42	0.08
SO_3	2.08	0.17
$K_2O + Na_2O$	1.21	1.49
Loss of ignition	-	0.82
C_3S	61.10	-
C_2S	17.00	-
C_3A	05.10	-
C_4AF	12.09	-
Specific gravity (g/cm^3)	3.10	2.65
Specific surface (m^2/kg)	380	800

Table 2 Chemical compositions of firebricks used

	BR(Al)	BR(Mg)	BR(Zr)
MgO	-	**≥ 96 %**	-
SiO_2	-	≤ 2 %	≤ 12 %
Fe_2O_3	≤ 2%	-	-
Al_2O_3	≥ 40%	-	**trace**
Na_2O_3	-	-	**≤ 1 %**
SO_4^{-2}	trace	**4.52**	**0,58**
Cl^-	0.003	0.014	0.028
$CaCO_3$	trace	**trace**	**trace**
ZrO_2	-	-	**≥ 40 %**
Specific surface (m2/kg)	500	550	510

According to images, it is clear that all the bricks have a typical structure of ceramic, i.e. they have the grain boundary and composed by polycrystalline [16]. However, the magnesium-based brick (BR (Mg)) contains micropores in its structure (Fig. 4). While that brick based on alumina has a specific structure in the alumina (Fig. 3). The zirconium brick is known for its great compactness and generally has a very low porosity (<1% according to the literature) compared to other bricks, which is shown in Fig. 3. It was noted that previously studies are confirmed that the powder of ceramic wastes have an important pozzolanic reactivity [17-18].

2.2 Mix design of studied concretes

In first, a composition of control concrete based on silica fume was established using the formulation of CimBeton [19]. After, three compositions of concrete (UHFRPC) were developed based on three types of waste refractory bricks (finely ground), the dosage of each type of brick is kept constant with the same dosage of silica fume used for the control concrete. The water–binder ratio, other compounds and superplasticizer dosage are kept constant (W/B =0.19). Also, the mixing process was kept constant for all mixtures. Table 3 shows the mixes details of studied concretes

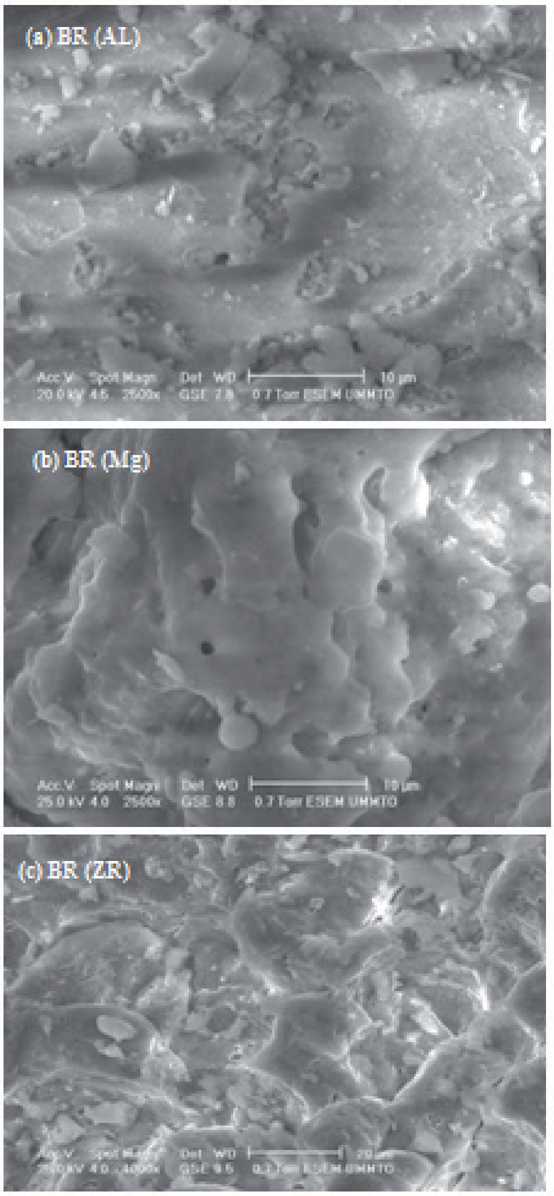

Fig. 4 SEM images of the refractory brick wastes used

Table 3 Details of concrete mixtures

	C (Kg)	FDS (Kg)	DS (Kg)	SF (Kg)	RWB (Kg)	PF (Kg)	SP (ext. sec)
CC	710	1020	215	230	-	1	12
CRWB1	710	1020	215	-	230	1	12
CRWB2	710	1020	215	-	230	1	12
CRWB3	710	1020	215	-	230	1	12

Notation: CC: Control Concrete with silica fume; CRWB1: Concrete with refractory waste brick based alumina; CRWB2: Concrete with refractory waste brick based magnesium; CRWB3: Concrete with refractory waste brick based Silica-Zirconium

2.3 Test methods

To perform the experimental study, prismatic samples (40x40x160 mm^3) were manufactured for each mixture. One day after casting, samples were stored in water under 21±1 °C. The other specimens same formulation of HPFRC, were subjected to a suitable heat treatment (60 °C for 8 h) at 7 days curing in water, then these test specimens were stored yet in water for 28 days [14, 20]. The various tests and measurements were carried out in order to evaluate the fresh and hardened properties.

Tests on fresh concrete: the flow test was carried out on the studied concretes, by the mini-cone used for cement pastes and mortars. The slump was measured at 20 °C, using mini-cone it was carried on fresh concretes for each mixture. The flow test procedure was according to Specification and guidelines for self compacting concrete (EFNARC) [21].

Tests on hardened concrete: Both the compressive and flexural strength of concrete were determined. A compressive test machine was used to test concrete samples, which have been cured in saturated water at 21± 1 °C for 2, 7 and 28 days according to ASTM C348 and C349 [22-23]. The bulk density is also measured for all studied concretes, according the ASTM test C642 [24].

3 Results and discussions

3.1 Fluidity of Concretes (flow testing standard)

The test results of concrete fluidity tested by mini-cone are given in Fig. 5. According these figures, all concretes exhibit fluidity suitable for fluid concretes and which varies between 19 and 21 cm. However compared to control concrete (CC), a slight decrease in the flow of CRWB2 and CRWB3 have been recorded. This can be explained by the powders used have a high specific surface, which requires a water excess.

3.2 Bulk density

Figure 6 give the bulk density of studied concretes measured after 28 days of curing age. From the results obtained, the UHPC have the same density whatever the nature of the refractory brick powder used. However, concretes elaborated with the refractory brick (based Zirconium-silica), gives a slightly higher density as compared to other concretes. This is explained by the specific mass of the brick based on silica and zirconium.

Fig. 5 Fluidity test by mini-cone

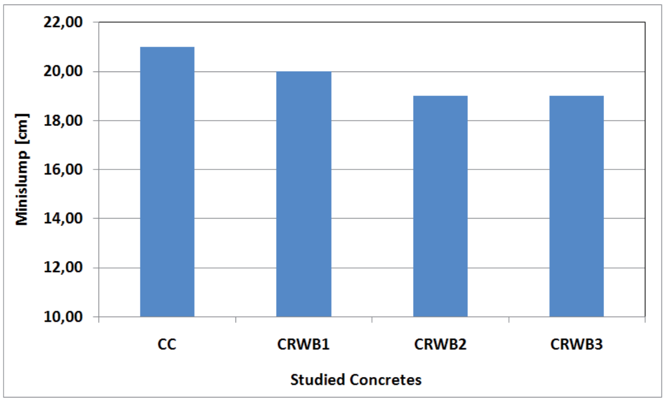

Fig. 6 Slump of studied concretes

3.3 Flexural Strength

Figure 7 shows evolution of flexural strength for all studied concretes at different age of curing. According to the results, it is evident that the tensile strength increases as a function of curing age for all concretes. However, the flexural strength decreases depending on the type of used brick powder. Against by, the concrete with brick based on magnesia (CRWB2) gives strength close to that the control concrete. The maximum value of the tensile strength recorded is that of the control concrete, it is around 14 MPa [15-17].

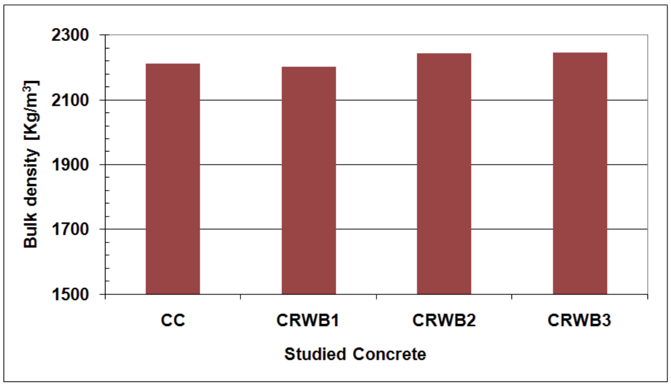

Fig. 7 Bulk density of Concrete studied

3.4 Compressive Strength

Test compressive strength results are shown in Fig. 8. It was remarkably that the compressive strength is decreased with the nature of used brick type at whatever curing age. It should be noted that this strength reduction is slight compared to control concrete.

An attempt was made to improve the compressive strength of UHPC prepared by the heat treatment. Recall that the heat treatment chosen is the one mentioned in paragraph (drying specimens at 60 °C for 8 h). Figure 9 shows the compressive strength with and without heat treatment measured at 28 days. According to the results, it was noted that the strength is significantly enhanced in the temperature effect for all concretes. This is explained by the beneficial effect of the temperature which have accelerates the cement hydration reactions [11, 14, 25-26]. The latter can generate the formation of a new CSH (Calcium-Silicate-Hydrate) and increasing the strength of concrete.

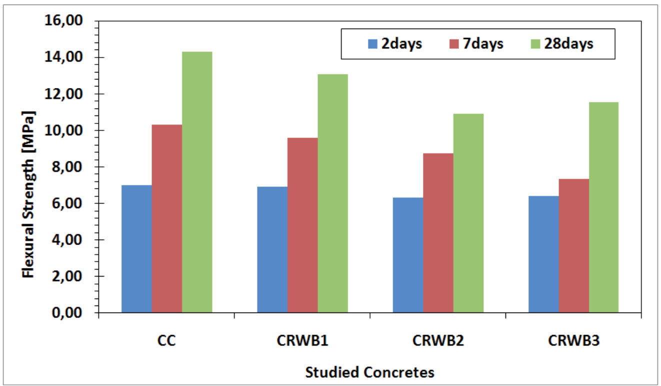

Fig. 8 Flexural strength evolution of concrete as function on curing age

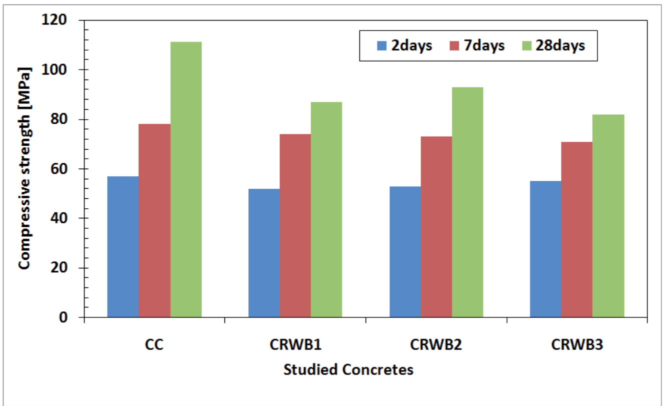

Fig. 9 Compressive strength evolution of concrete as function on curing age

4 Conclusions

This study has presented an experimental investigation on the reuse of refractory brick wastes as a supplementary cementitious material to produce an ultra high performance concrete (UHPC). The conclusions which could be cited are as follows;

- All studied Concretes have same bulk density regardless of the nature or type of firebrick powders used by the silica fume substitution;
- Test results of fluidity by mini-cone, were shown that all concretes have a fluidity which varies between 19 and 21 cm corresponding to fluid concretes (UHPC). A slight decrease of fluidity for the concretes CRWB1 and CRWB3;
- Test results of fluidity by mini-cone, were shown that all concrete have a spread which varies between 19 and 21 cm diameter corresponding to a UHPC. The fluidity of UHPC was slightly decreased to CRWB1 and CRWB3;
- The largest recorded value of compressive strength is about 120 MPa for the control concrete, and the smallest value is the order of 82 MPa for the CRWB3. However, the CRWB1 gave a higher value of compressive strength compared to CRWB3 and CRWB2;
- The compressive strength is significatly improved by the heat treatment applied. This proves the beneficial effect of temperature which accelerates cement hydration reactions.
- The CRWB1 gave a higher strength than that concrete CRWB2 and CRWB3; it is in the order of 93 MPa. Given the cement content used for these concretes and also W/C ratio = 0.3, the obtained compressive strength values are acceptable.

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