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Recycled Refractory Brick as Aggregate for Eco-friendly Concrete Production

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Abstract

The amount of construction and demolition waste continues to increase year by year. These wastes have a significant harmful influence on the environment; refractory brick is among of these wastes. This paper concerns the reuse of refractory brick wastes to produce an eco-friendly concrete. To achieve this objective, coarse and fine Natural Aggregates (NA) were partially replaced with recycled Refractory Brick Aggregates (RBA). According to the design of experiment, two families of mixes were prepared and tested: the first mixes was made with coarse and fine NA (as reference concrete) and the second mixes made by replacing 20% of coarse and fine NA by coarse and fine RBA. For each of the mentioned families, three cement dosages of 350 kg/m^3, 400 kg/m^3, 450 kg/m^3 were investigated. A series of experiments including water porosity, density, Ultrasonic Pulse Velocity (UPV) and compressive strength were assessed. Observed results indicate that the use of coarse and fine RBA had a relatively influence on the water porosity and UPV of concrete. However, the use of coarse and fine RBA produces a slightly decreased the density of concrete (below 2%). Moreover, the use of coarse and fine RBA in concrete improved the compressive strength. Hence, coarse and fine RBA can be successfully used to produce concrete with acceptable properties.

1. Introduction

At present, the consumption of concrete has increased proportionately with civilized growth and the increase in the world population, which is causing massive pressure on natural resources. Also, a large amount of concrete waste from demolition and construction is dumped in landfills. From the viewpoint of environmental preservation and protecting natural resources, this situation is a good incentive to recycle and reuse construction and demolition wastes. In recent years, many researchers have evaluated the use of construction and demolition wastes as aggregates in concrete production, which shows that it can be used to replace natural aggregates [1-7].

This research focuses on the important environmental problem of how to deal with refractory brick waste. Refractory bricks are mainly used especially within the furnace's basin such as cement, glass and ceramics. The use of refractory bricks wastes as aggregates are environmentally and economically important and help to reduce the consumption of raw materials. The recycled refractory brick can be used in the concrete as aggregate (fine or coarse) or as supplementary cementitious.

Limited studies on the physical and mechanical properties of concrete or mortar made with refractory bricks waste have been performed. A study has been initiated by Kavas et al. 2006 [8], who investigated the use of magnesium-chromite and alumina-based refractory wastes as fine aggregates to produce high temperature resistant mortar. The result obtained by the authors shows that the properties of magnesium chromite based refractory waste aggregate, have given the best results.

Saidi et al. 2015 [9] studied the effect of introducing refractory brick waste to produce cement mortar and noted that up to 20% of it significantly increased the compressive strength and recommended the use of refractory brick waste as fine aggregate. Aboutaleb et al.2017 [10] found that the refractory brick could be used successfully as a fine aggregate for self-compacting mortar manufacture.

Nematzadeh and Nasiri, 2017 [11] produced concrete containing 0, 25, 50, 75, and 100% of fine refractory brick wastes. The samples were heated from 20 to 1000°C. The results illustrated that concrete made with 100% fine recycled refractory brick performed better than concretes made with natural aggregates at higher temperatures. However, Nematzadeh et al, 2018 [12] found that the performance of concrete made with fine recycled refractory brick was rather unsatisfactory in the acid environment. Zeghad et al, 2017 [13] referred that the refractory brick wastes can be used as cementitious material or additions for reinforced high-performance concrete manufacture.

There are also some researches on the use of refractory brick wastes as coarse aggregates in concrete. Khattab and Hachemi, 2021 [6] have evaluated the performance of concrete made with the replacement of natural coarse aggregates by recycled refractory bricks. The recycled refractory bricks came from two different sources. The authors found that the performance of recycled brick concrete depends on the quality and porous nature of recycled refractory bricks. Furthermore. Khattab and Hachemi, 2021 [6] state additionally that, concrete made with 20% coarse recycled refractory brick has been graded as good quality with acceptable properties.

To summarize, a number of researchers have focused on the properties of concrete and mortars made with RBA as aggregate (coarse or fine) or additions. However, no attention has been directed at studying the performance of concrete made with coarse and fine RBA, it is interesting to investigate the potential of using refractory brick as coarse and fine aggregate to produce concrete. For this reason, this research aims to produce concrete by using recycled refractory brick as coarse and fine aggregate by partial substitution of coarse and fine natural aggregate at the replacement level of 20%. Concretes produced were compared with the conventional concrete in terms of physical and mechanical properties (water porosity, density, Ultrasonic Pulse Velocity (UPV), and compressive strength).

2. Experimental research program

2.1. Materials

2.1.1. Cement

The cement used in this study was Portland cement (CPJ CEM II/A 42.5). The chemical composition and mechanical properties of this cement were measured in the LPCMA laboratory in Biskra, and the results are presented in Table 1.

Table 1. Chemical composition and mechanical properties of cement.

Chemical composition of cement (%)			
CaO	61.40	MgO	1.32
SiO_2	16.79	SO_3	3.33
Fe_2O_3	3.07	K_2O	0.72
Al_2O_3	4.54	Na_2O	0.21

Mechanical properties (MPa)	2 days	7 days	28 days
Compressive strength	18.2	30.40	35
Flexural strength	1	1.39	2.7

2.1.2. Aggregates

For the present research, the crushed stone was used as natural coarse aggregates, mainly constituted of calcareous, their granular class and water absorption are 5/15 mm, 0.22% and 15/25, 0.26%. The siliceous sand was also used as the natural fine aggregate, with the maximum grain size, fineness modulus and water absorption of 5 mm, 2.51 and 0.65 %, respectively.

In this study, recycled Refractory Brick Aggregate (RBA) was employed, and it was sourced from wastes of cement factory after use in the furnace basin. The RBA used in this work were prepared by a two-stage crushing process:

1- Primary crushing was performed on the big blocks of refractory bricks using a small jaw crusher to obtain into smaller ones.
2- After primary crushing, refractory brick was subjected to a crushing process using a Los Angeles abrasion machine.

The RBA was then sieved and separated into two categories: For the first category, coarse RBA their granular class and water absorption are 5/15 mm, 2.88%, and 15/25, 3.53%, see Figure 1.a. For the second category, fine RBA with maximum grain size, fineness modulus and water absorption of 5 mm, 2.60 and 4.32 %, respectively, see Figure 1.b. Figure 2 illustrates the grain size distribution of natural and recycled refractory brick aggregates according to P 18-560 [14].

(a)

(b)

Figure 1. Recycled refractory brick aggregate: (a) coarse (b) fine

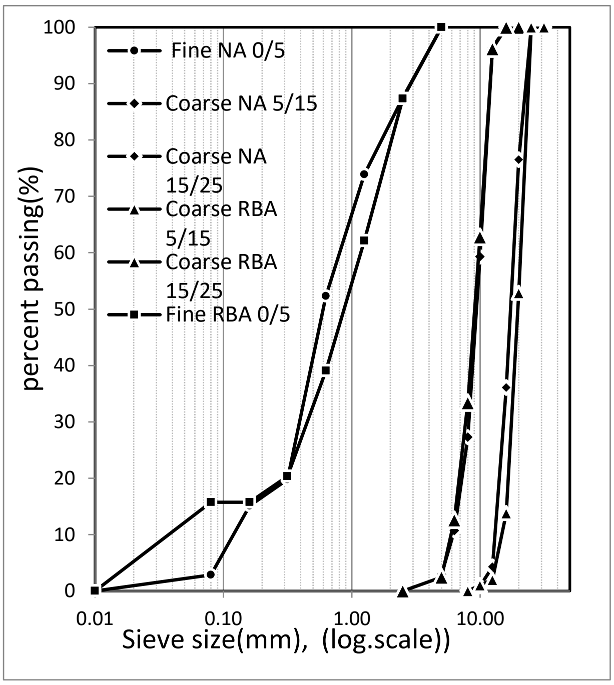

Figure 2. The grain size distribution for the natural and recycled refractory brick aggregates.

The physical properties of natural and recycled aggregates determined according to the following standards: NF P 18-554 [15], NF P 18-555 [16], NF P 18-573 [17], NF P 18-598 [18], and results obtained are listed in Table 2. Moreover, a Scanning Electron Microscopy (SEM) was used to observe the microstructure of RBA, and the results obtained are shown in Figure 3.

Table 2. Results of the physical properties of the natural and recycled refractory brick aggregates.

Physical properties	coarse NA		coarse RBA		fine NA	fine RBA
	15/25 mm	5/15 mm	15/25 mm	5/15 mm	0/5 mm	0/5 mm
Water content (%)	0.10	0.11	0.06	0.06	0.08	0.09
Los Angeles abrasion	30		58		-	-
Sand equivalent (%)	-		-		75.8	82.6
Finesse modulus	-		-		2.51	2.60

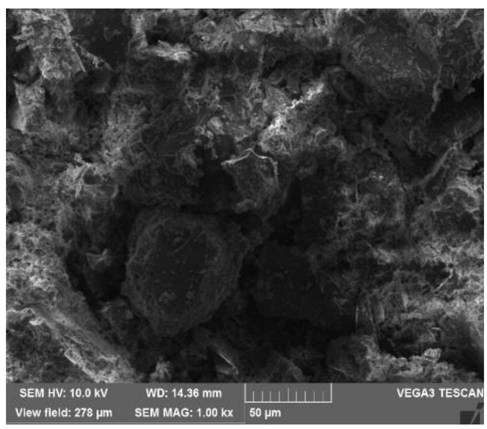

Figure 3. The SEM images of recycled refractory brick

It can be observed that the coarse and fine RBA have higher density, water absorption and porosity than the coarse and fine NA. In the abrasion test, the coarse RBA have a high percentage of loss weight.

2.1.3. Superplasticizer

In order to obtain the same workability without increasing the water content, a superplasticizer (GLENIUM® 27) was used for concrete with w/c = 0.38. The superplasticizer has the following properties: density is 1.05 ± 0.02 and ph value is 6.0 ± 1, the recommended range of use is 0.3% to 3% of the weight of the cement.

2.2. Design of Concrete Mixtures

Two types of concrete families with dosages of cement of 350 kg/m^3, 400 kg/m^3, and 450 kg/m^3 were made. The details of mix formulations are contained in Table 3. As seen in Table 3, each mixture was based on the designation ‘‘CA-B’’, where "C" for concrete, ‘‘A’’ indicates the family No. and ‘‘B’’ indicates cement dosage. The first family, of three control mixtures (C1-350, C1-400, and C1-450) was manufactured with coarse and fine natural aggregate and they are determined based on the Dreux mix design method [19]. For the second family, three mixtures (C2-350, C2-400, and C2-450) were produced by replacing 20% (by volume) of coarse and fine NA by coarse and fine RBA. The percentage of coarse and fine RBA used was taken from the results of the previous studies [6] and [9], respectively.

It should be pointed that, coarse and fine RBA have a much higher water absorption than that of coarse and fine NA, respectively. Which is important during the process of mixing concrete and we can be overcome this problem by following methods:

1- Extra water is added corresponding to the water absorbed by the fine RBA.

2- Coarse RBA were soaked in water for 4 hours then air-dried to a saturated dry condition before mixing with other ingredients of concrete [7].

Table 3. Composition of all mixes produced (kg/m^3).

Mixture	C	W	Extra water	w/c	Fine NA (mm)	Fine RBA (mm)	coarse NA (mm)		coarse RBA (mm)		Sp (%)
					0/5	0/5	5/15	15/25	5/15	15/25	
C1-350	350	206.50	-	0.59	688.34	-	226.63	947.84	-	-	-
C1-400	400	190.48	-	0.47	654.83	-	239.88	926.06	-	-	-
C1-450	450	173.08	-	0.38	639.43	-	180.18	958.54	-	-	1.4
C2-350	350	206.50	6.95	0.59	550.67	160.08	181.31	785.27	48.93	203.89	-
C2-400	400	190.48	6.58	0.47	523.86	152.29	191.91	740.85	51.79	199.20	-
C2-450	450	173.08	6.42	0.38	511.54	148.70	144.15	766.83	38.90	206.19	1.4

C: cement, W: water, w/c: water/cement ratios, Sp: Superplasticizer

2.3 Specimen Preparation

For each type of concrete mixture prepared in the previous section, three specimens were cast into cubic steel molds with dimensions 10 cm x 10 cm x 10 cm and duly was compacted by a vibrating table. After 24 h, the specimens were demoulded and cured under water at an average temperature of 20 ± 2 °C for 28 days. At the age of 28 days, the specimens were prepared and used to determine water porosity, density, Ultrasonic Pulse Velocity (UPV), and compressive strength.

2.4. Tests on concrete mixes

In order to examine the specimens containing both coarse and fine RBA, their physical and mechanical properties including the water porosity, density, ultrasonic pulse velocity and compressive strength were evaluated.

2.4.1 Density and water porosity

The density and water porosity of different concretes were evaluated following NF EN 12390-7 [20]. The dried mass (Ms) of concrete specimens was obtained after drying in the oven at 60°C ±2°C for a constant mass. Then, the samples were immersed in water and weighed regularly until completed saturation. The immersed mass (Mw') was measured using a hydrostatic balance. Finally, the saturated mass (Mw) was determined after wiping samples for removing excess water on the surface. Three samples were tested for each concrete mixture. Water porosity and density are determined according to below the equations

$$P = (Mw - Ms)/(Mw - Mw`) \qquad (1)$$

$$D = Ms/(Mw - Mw`) \qquad (2)$$

Where P is water porosity, D is density

2.4.2 UPV

The UPV was considered as a non-destructive method for assessing the homogeneity and quality of concrete according to the AFNOR P 18-418 specifications [21]. The value of UPV can be calculated from the path length divided by the measured time. For each mixture, three cubes were tested and the results were averaged.

2.4.3 Compressive strength

Finally, the test method specified in NF EN 12390-3 [22] was carried to determine the compressive strength. The test was performed on three cubic specimens of each concrete mixture at the age of 28 days by using a hydraulic press with a maximum load capacity of 3000 KN. Furthermore, the loading rate of compressive was taken constantly at 0.5 MPa/s for all the specimens according to standard NF EN 12390-4 [23].

3. Results and discussion

3.1. Water porosity

Results of the water porosity of the various mixes are presented in Figure 4. As shown in the figure, the water porosity of the concrete mixtures prepared with 20% coarse and fine RBA was higher than the corresponding concrete mixtures prepared with natural aggregate. For example, the water porosity of C2-350, C2-400 and C2-450 increased by 27%, 14% and 32%, respectively, compared to the control mixtures. This confirms that coarse and fine RBA are more porous than those coarse and fine NA, respectively. As stated before, the coarse and fine RBA shows a higher porosity and water absorption than natural aggregate, which can adversely affect the water porosity of concrete.

In the tests carried out, it could be observed that increasing the cement content from 350 to 400 and 450 kg/m^3 decreased the porosity of the concretes prepared with coarse and fine RBA as shown in Figure 4. This can be explained by the that increased cement content can transform large capillary pores of the concrete, resulting from the inclusion of coarse and fine RBA into smaller ones by fill the voids.

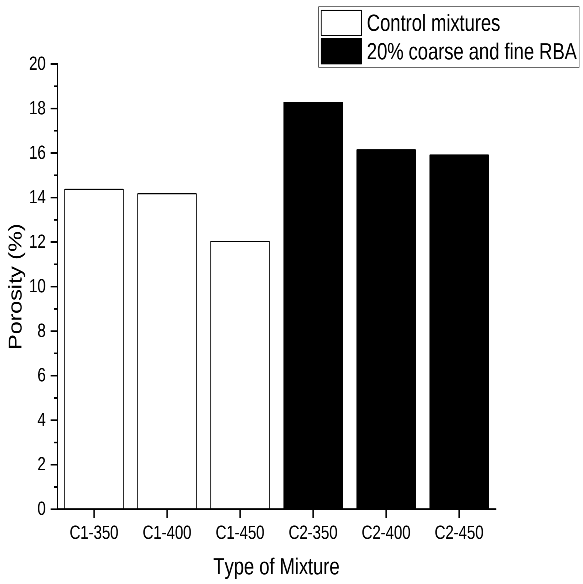

Figure 4. Effect of coarse and fine RBA on porosity.

3.2. Concrete density

Figure 5 outlines the results of all the density tests obtained for different studied mixtures. The results obtained show that a slight influence of the coarse and fine RBA inclusion on the density of concrete can be seen. Concretes containing 20% of coarse and fine RBA show a reduction of the density of about 2% for C2-350, 1% for C2-400 and 1% for C2-450 compared to the control mixtures. In other words, the inclusion of coarse and fine RBA has a slight influence on the decrease of the density of concrete, which might be attributed to the high density of coarse and fine RBA.

As stated above, the density of concrete mixtures prepared with coarse and fine RBA was good and comparable with the reference concrete. The study initiated by Aboutaleb et al [10] shows that the sand substitution by refractory brick does not a great effect on the bulk density of mortar.

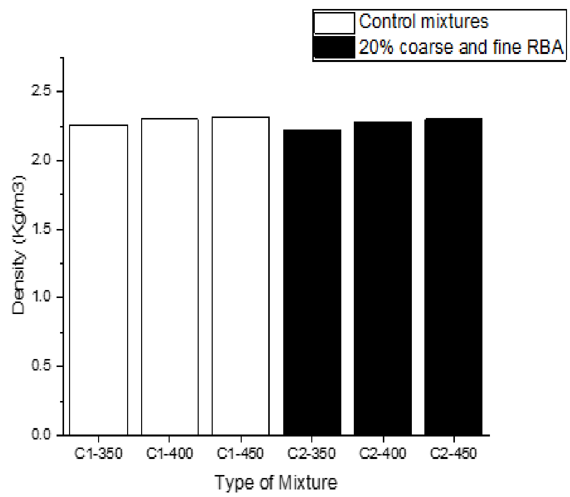

Figure 5. Effect of coarse and fine RBA on density.

3.3. UPV

The UPV is used in order to assess the uniformity and detecting cracks and voids of concrete. Concrete quality classified by UPV value, it is known if the value is above 4.5 km/s the concrete class (excellent), between 3.5 and 4.5 km/s the concrete class (good), between 3.0 and 3.5 km/s the concrete class (medium) and less than 3.0 km/s the concrete class (doubtful) [24]. The UPV results of the various specimens are given in Figure 6.

As can be seen in the results of the current study, a reduction of the UPV was observed for concrete prepared with 20% coarse and fine RBA compared to mixtures prepared with natural aggregate, which can be explained by the high porous structure of coarse and fine RBA. It is showed that, for specimens containing 20% coarse and fine RBA, the UPV reaches a loss of 6 % for C2-350, 7% for C2-400, and 3% for C2-450 compared to the control mixtures. Considering the concrete prepared with coarse and fine RBA it was found that the UPV values are greater than 3.5 km/s, which can be classified as a good quality concrete.

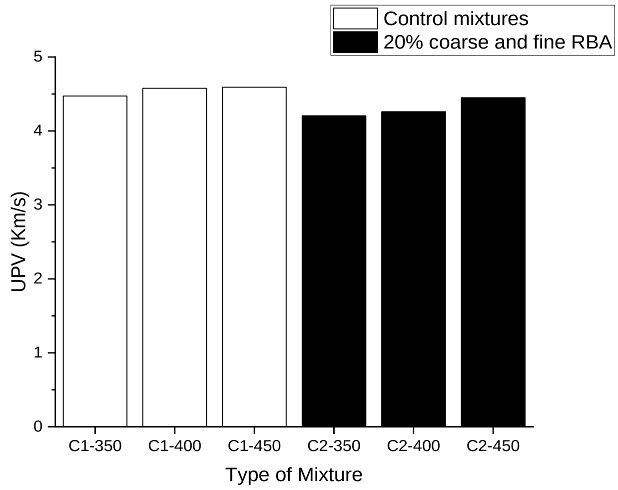

Figure 6. Effect of coarse and fine RBA on UPV.

3.4. Compressive strength

Figure 7 shows the test results of the compressive strength of all prepared concrete. As can be seen in the results of the current study, a slight increase in compressive strength is observed for concrete prepared with 20% coarse and fine RBA compared to concrete prepared with natural aggregates. This increase is 9% for C2-350, 1% for C2-400, and 5% for C2-450 compared to the control mixtures. This means that the incorporation of coarse and fine RBA imposes a positive effect on the compressive strength of concrete, which might be attributed to the high density of coarse and fine RBA. Similar results were observed by Saidi et al. [9] who reported that the replacement of the natural fine aggregate by up to 20% recycled refractory bricks shows a positive influence on the compressive strength of mortar.

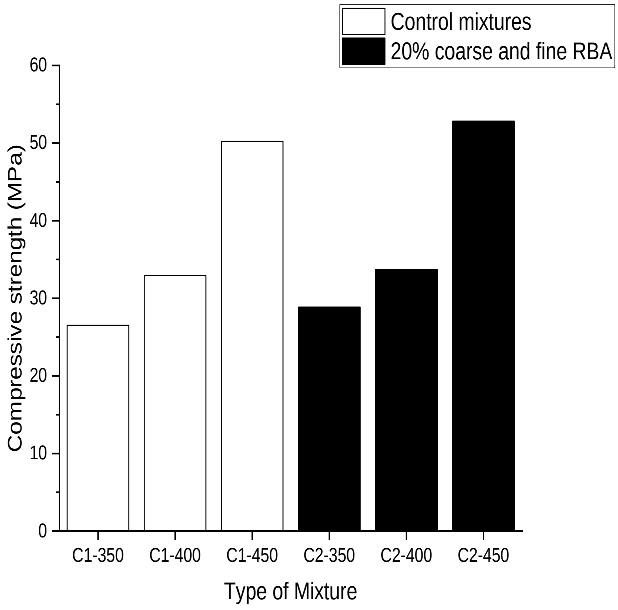

Figure 7. Effect of coarse and fine RBA on compressive strength.

4. General Conclusion

Based on the results of the study, the following conclusions can be drawn:

- The coarse and fine RBA has an inferior quality compared to natural aggregate.
- The use of coarse and fine RBA has a significant influence on the porosity of concrete was observed (between 14 and 32%).
- The inclusion of coarse and fine RBA as a partial replacement of coarse and fine NA in concrete has a negligible effect on density.
- The concrete made with coarse and fine RBA is good in terms of its UPV value compared with control mixtures; their UPV value is greater than 3.5 km/s.
- Compressive strength does not seem to be affected by coarse and fine RBA incorporation compared to control mixtures. It is important to note that concrete made with coarse and fine RBA presents higher compressive strength than that of concretes with coarse and fine NA.
- There are several ways to improve the quality of concrete made with coarse and fine RBA such as increasing the amount of cement and decreasing w/c.
- Finally, coarse and fine natural aggregates can be partially replaced by refractory brick wastes in the manufacture of concrete, which not only effectively solves the construction waste pollution problem, but also provides sustainable alternatives to protect natural resources.

It can be concluded that concrete made with coarse and fine RBA have a satisfactory performance than concrete made with natural aggregate, which might be attributed to the high density of these aggregates. Another research is carrying out for concrete containing coarse and fine RBA at high temperature, it is necessary to understand the performance of this type of concrete when exposed to fire.

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Acronyms list: NA- Natural Aggregates; RBA- recycled Refractory Brick Aggregates; UPV- Ultrasonic Pulse Velocity

Conflict of Interest

No potential conflict of interest was reported by the authors.

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