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MECHANICAL PROPERTIES AND DURABILITY OF CONCRETE WITH PARTIAL REPLACEMENT OF PORTLAND CEMENT BY CERAMIC WASTES

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ABSTRACT

The ceramic industry is known to generate large amounts of calcined-clay wastes each year. So far a huge part is used in landfills. Reusing these wastes in concrete could be a win-win situation. For one hand by solving the ceramic industry waste problem and at the same time leading to a more sustainable concrete industry by reducing the use of non renewable resources like cement and aggregates and avoiding environmental problems related to land filled wastes. This paper examines the feasibility of using ceramic wastes in concrete. Results show that concrete with 20% cement replacement although it has minor strength loss possess increase durability performance. Results also shows that concrete mixtures with ceramic aggregates perform better than the control concrete mixtures concerning compressive strength and chloride diffusion.

Keywords: Concrete; ceramic wastes; mechanical properties; durability performance

INTRODUCTION

In Europe the amount of wastes in the different production stages of the ceramic industry reaches some 3 to 7% of its global production meaning millions of tons of calcined-clays per year that are just land filled [1]. With increasing restrictions on landfills in European Union area, the cost of deposition will increase and the industries will have to find ways for reusing their wastes. Although the reutilization of ceramic wastes and has been practiced, the amount of wastes reused in that way is still negligible. Hence, the need for its application in other industries is becoming absolutely vital. Construction industry as the end user of almost all the ceramic materials is well posed to solve this environmental problem which is partly its own. The nature of construction industry, especially the concrete industry, is such that ceramic wastes can be used safely with no need for dramatic change in production and application process. On one hand, the cost of deposition of ceramic waste in landfill will be saved and, on the other, raw materials and natural resources will be replaced, thus saving energy and protecting the environment. According to some authors the best way for the construction industry to become a more sustainable one is by using wastes from other industries as building materials [2,3]. The production of cement requires high energy input (850 kcal per kg of clinker) and implies the extraction of large quantities of raw materials from the earth (1,7 tonnes of rock to produce 1 tonne of clinker). On the other hand the production of one tonne of cement generates 0,55 tonnes of chemical CO_2 and requires an additional 0,39 tonnes of CO_2 in fuel emissions, accounting for a total of 0,94 tonnes of CO_2 [4]. Therefore, the replacement of cement in concrete by ceramic wastes represents a tremendous saving of energy and has important environmental benefits. Several authors already confirmed the pozzolanic reactivity of ceramic wastes [5-7], nevertheless, research carried out so far by reusing ceramic wastes in concrete are scarce and do not evaluate concrete durability performance which is a key issue. On the other hand, recent research in the field of reusing ceramic aggregates in concrete are scarce and do not evaluate concrete durability performance [8,9]. Consequently the aim of this research project is the assessment of the properties and durability of of ceramic waste based concrete.

Experimental work
Materials and concrete mix design

The chemical compositions of ceramic pastes were analysed and results obtained are reported in Table 1. The silica and alumina are the most significant oxides present in the ceramic pastes. The variation of proportion of the silica and alumina is due to the clay used. It should be noted that the red paste shows high proportion of iron oxide responsible for the red colour of the products. Ceramic wastes were crushed with a jaw crusher to make the ceramic aggregate. Thus, by using this system to crush ceramic wastes it is possible obtain coarse aggregates, fine aggregates and ceramic powder that after sieving can be used without additional work and with minimal cost implications.

Table 1 - Chemical composition of ceramic pastes

Type	$Si0_2$	Al_20_3	Fe_20_3	Ca0	Mg0	Na_20	K_20	$Ti0_2$
Red paste twice fired ceramic	51.7	18.2	6.1	6.1	2.4	0.2	4.6	0.8
White paste once-fired ceramic	58.0	18.0	1.0	8.3	0.6	0.2	1.2	0.8
White paste for twice -fired ceramic	59.8	18.6	1.7	5.5	3.5	1.6	2.5	0.4
Red paste for stoneware tile	29.1	20.3	7.7	1.2	1.1	0.4	4.2	0.9
White paste for stoneware tile	65.0	21.3	1.3	0.2	0.3	2.5	3.7	0.2
White paste for sanitary ware	65.8	22.2	0.6	0.1	0.1	1.0	3.5	0.3

At laboratory scale the ceramic wastes were grounded with a ball mill with metal balls to obtain ceramic powder. The ceramic powders with a particle size <75µm were chosen for the partial substitution of cement. The coarse aggregate and the coarse sand used in the concrete mixes with cement replacement by ceramic powder were crushed granite aggregates. For the production of concrete samples in phase A, Portland cement, CEM I-32.5, complying with the NP EN 197-1:2001was used along with both natural sand and granite aggregates. The concrete mixes were determined using the Faury method, applying a computer programme [10,11]. A mix design, with characteristic strength f_c=25N/mm^2 and a target mean strength f_m=30 N/mm^2 was studied. Four mixes with 20% replacement of cement by ceramic powder were also prepared. Each one is named after the source of the ceramic waste: CB (ceramic bricks); WSTF (White stoneware twice-fired); SW (sanitary ware); WSOF (White stoneware twice-fired). The compositions of the concrete mix used in phase A are described in Table 2.

Table 2-Concrete mix proportions per cubic meter of concrete used in phase A

Control mix		Concrete mixtures with ceramic wastes	
Portland Cement	350.0 Kg.	Portland Cement	280.0 Kg.
Coarse aggregate	1084.0 Kg.	Ceramic waste powder	70.0 Kg.
Fine sand	135.4 Kg.	Coarse aggregate	1084.0 Kg.
Coarse sand	564.0 Kg.	Fine sand	135.4 Kg.
Water	218.5 l	Coarse sand	564.0 Kg.
W/C	0.6	Water	218.5 l

The equivalent ceramic aggregate concrete for each mix was obtained by replacing the natural aggregates with an equal volume of crushed ceramic, everything else remained the same. To have a direct comparison of concrete made with crushed-ceramic aggregate with conventional concrete, two corresponding mixes were prepared one replacing natural sand by ceramic sand (MCS) and other where coarse granite aggregate where replaced by ceramic coarse aggregate (MCCA). The ceramic aggregates were soaked in water for 24 hr and then air-dried to a saturated surface dry condition before mixing with other ingredients. For the production of concrete samples in phase B, Portland cement, CEM I-42.5, complying with the NP EN 197-1:2001was used. The concrete mixes were determined using the Faury method, applying a computer programme. The compositions of the concrete mix used in phase B are described in Table 3.

Table 3 - Concrete mix proportions per cubic meter of concrete in phase B

Materials	Control	MCS- Mix with ceramic sand	MCCA- Mix with ceramic coarse aggregate
CEM-II 42,5	350	350	350
Sand	861	-	861
Ceramic sand	-	729	-
Coarse aggregate	958	958	-
Ceramic coarse aggregate	-	-	820
Water	175	175	175
W/C	0,5	0,5	0,5

Experimental procedures

Compressive strength

The compressive strength was determinate following the NP EN 12390-3:2003. The specimens were conditioned at a temperature equal to 18 ± 1 ºC cured under water until they have reached the testing ages. Tests were performed on 100x100x100 mm^3 specimens. Compressive strength for each mixture was obtained from an average of 3 cubic specimens determined at the age of 7,14, 28, 56 and 90 days of curing.

Durability aging test

The aging test performed is composed by twelve cycles; each cycle has 4 steps and one conditioning period (Table 4).

Table 4-Durability aging test phases

Principal phase			
Exposure	Temperature	Relative Humidity	Duration
Dry Heat	75±2 ºC	45%	90 min
Cold	-10±2 ºC	---	90 min
Wet Heat	55±2 ºC	95%	90 min
Cold	-10±2 ºC	---	90 min
Conditioning phase			
Conditioning	23±2 ºC	50%	960 min

The different phases have been selected to simulate dry heat, cold weather and wet heat and cold. Further the rapid change of temperature from 75ºC to –10ºC and then from –10ºC to 55ºC and dropping quickly to –10ºC in each cycle to simulate the thermal shock that concrete can suffer. Following the curing period, all the specimens were weighed and half of the specimens were submitted to twelve cycles of aging 24 hours long each, the remaining specimens were kept in the curing chamber at constant 21ºC. All specimens were subjected to compressive strength test.

RESULTS AND DISCUSSION

Using ceramic powder as partial replacement of cement

Compressive strength,

The results obtained indicate, as expected, large differences in early curing ages and smaller differences at long curing ages (Fig. 1). The concrete mixture with 20% of CB waste has the highest mechanical performance for all ceramic wastes which means it has higher pozzolanic reactivity. The concrete mixture with WSOF wastes has the worst mechanical performance at early ages, representing 74,8% of control strength for 7 days curing.

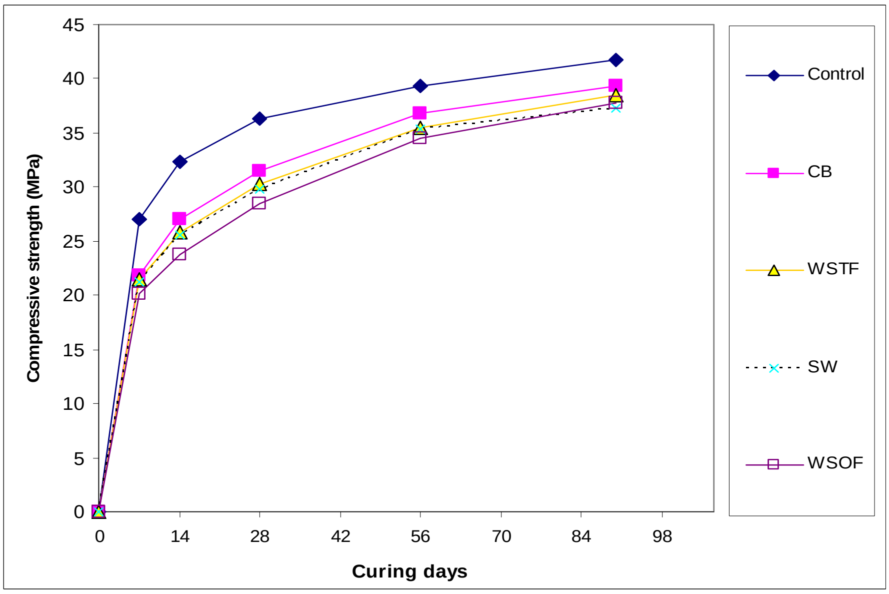

Figure 1 – Compressive strength at different curing ages.

For 28 days curing that concrete mixture has almost 80% of the control strength index. However, for 90 days curing the compressive strength activity index of the WSOF mixture reaches 90,4%.For long curing ages concrete mixtures with 20% cement replacement has minor the strength loss. Since higher curing temperatures increase the rate of pozzolanic activity pre-fabrication industry may be an ideal way to their employment. This is because higher curing temperatures are used in concrete pre-fabrication for accelerated demoulding.

Durability performance

As for the durability aging test (Fig.2), results indicate that all mixtures without exception have higher durability performance which confirms the positive impact of the ceramic additions.

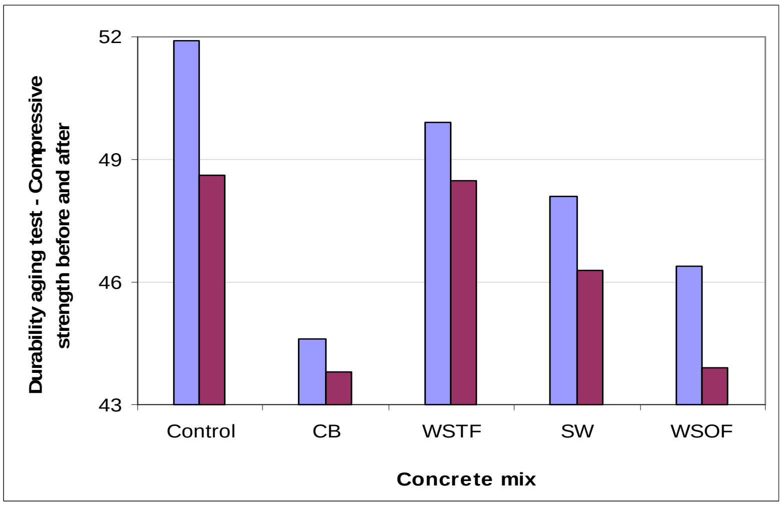

Figure 2 – Compressive strength: Before and after the durability aging test

Using ceramic aggregates replacing traditional aggregates

Compressive strength

The results obtained (Fig. 3) indicate that the strength is higher for concrete with both replacements coarse ceramic aggregate (MCCA) and ceramic sand (MCS) than control concrete with traditional aggregates.

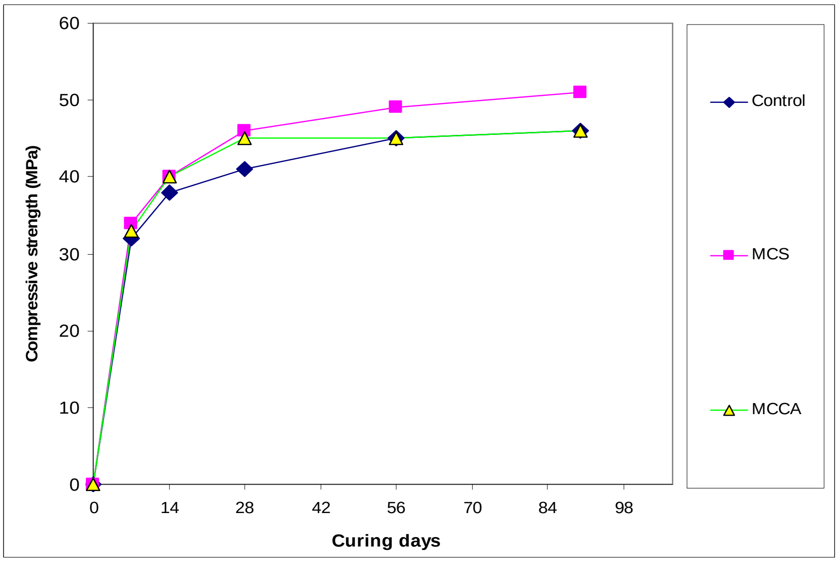

Figure 3 – Compressive strength

This behaviour is opposite to the one obtained by others using low percentage crushed brick aggregates [12,13]. One explanation for that may be due to the fact that they used brick aggregates with a water absorption level between 16% and 19%, which is much higher than the water absorption of the ceramic aggregates used in the present investigation. Another explanation relates to the fact that ceramic aggregates are used in a pre-saturated state they can provide water for cement hydration. Nevertheless, the strength performance is higher for concrete mixtures with ceramic sand beyond 14 days curing. As for concrete mixtures with coarse ceramic aggregate a maximum strength level is attained at 28 days curing.

Durability performance

As for the durability aging test (Fig.4) compressive strength reduction is higher for ceramic based concrete.

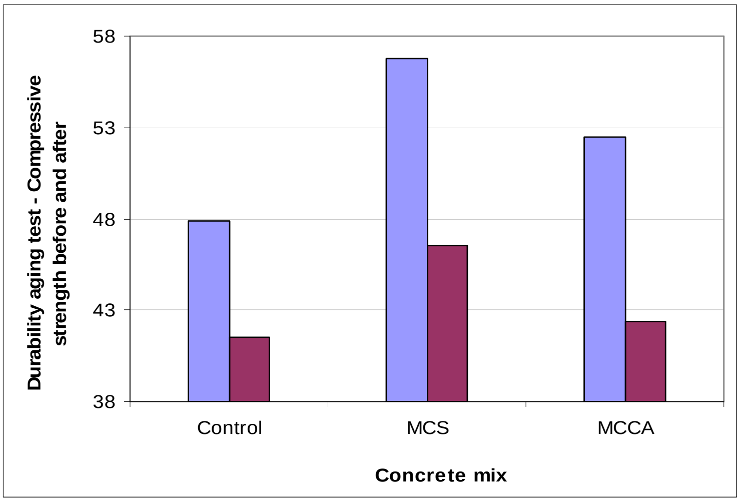

Figure 4 – Compressive strength: Before and after the durability aging test

Nevertheless, compressive strength after the aging test is still higher in ceramic based concrete. Therefore, the replacement of traditional sand in concrete by ceramic sand represents important environmental benefits. Avoids the extraction of large quantities of raw materials from the earth, avoid energy costs and also landfill problems.

CONCLUSIONS

Results show that concrete with ceramic waste powder although has minor strength loss possess increase durability performance. Results also show that replacement of traditional sand by ceramic sand is a good option because does not imply strength loss and has superior durability performance. As for the replacement of traditional coarse aggregates by ceramic coarse aggregates, the results are promising but require further investigations.

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