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NEW POZZANIC INDUSTRIAL WASTES FOR ECO-EFFICIENT CONCRETE

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Abstract. *Concrete is one of the most widely used construction materials in the world. However, the production of Portland cement as the essential constituent of concrete requires a considerable energy level and also releases a significant amount of chemical carbon dioxide emissions and other greenhouse gases (GHGs) into the atmosphere. Thus, seeking an eco-efficient and sustainable concrete may be one of the main roles that construction industry should play in sustainable construction. To make the concrete more eco-efficient, different life cycle phases of concrete products should be considered, such as extraction of raw material, production of constituents, production of concrete, transportation, erection, maintenance, deconstruction or demolition and recycling. Since binder production represents the major part of the environmental impacts , investigations on partial binder replacement by pozzolanic additions or use of environmental friendly binders lead to an eco-efficient concrete. The present study, as the preliminary results of a PhD research project, is an attempt to evaluate the pozzolanic reactivity of some industrial wastes, namely ceramic waste and slate powder, as well as the possibility of using such materials as partial replacement for Portland Cement. Results indicate that a high-strength eco-efficient concrete can be produced using slate powder or ceramic waste with metakaolin as Portland Cement replacement.*

1. INTRODUCTION

Concrete is the most widely used construction materials in construction industry. It is estimated that today's world concrete production is about 10 billion tons per year [1]. Concrete, comparing with many other building materials, is more durable and environmental friendly but the production of Portland cement as the essential constituent of concrete requires considerable energy, releasing a significant amount of carbon dioxide emissions and other greenhouse gases (GHGs) into atmosphere [2]. The production of one tonne of Portland cement generates 0,55 tonnes of chemical CO_2 and requires an additional 0,39 tonnes of CO_2 in fuel emissions for baking and grinding, accounting for a total of 0,94 tonnes of CO_2 [3]. Having said that Portland cement production represents 74-81% of the total CO_2 emissions of concrete, the aggregates represent 13-20%, therefore batching, transport and placement activities have no relevant expression in terms of carbon dioxide emissions [4,5].

Since binder production represents the major part of the environmental impacts of concrete this means that investigations on binder replacement by pozzolanic additions or about eco-efficient binders would lead to an eco-efficient concrete.

The durability of concrete structures plays also a major role in the eco-efficiency of concrete. In fact, current concrete structures presents higher permeability which allows water and other aggressive elements to enter. This leads to carbonation and chloride ion attack resulting in corrosion problems thus leading to expensive conservation actions or building new structures [6].

Furthermore, in general, sustainability promotes the utilization of alternative materials in the manufacturing of concrete products because it minimizes waste, encourages the recycling of unavoidable production of waste, into production process. It also reduces the use of primary materials, encourages the use of byproducts from other industries, while improving the quality and durability of products.

Besides all abovementioned points, concrete is a material which its components can be obtained locally so it would be an appropriate approach to investigate new supplementary cementitious materials in local industries or natural resources. This may reduce the cost of SCM and the cost of transportation of such materials as well.

Dealing with the issue of industrial wastes, per se, is one of the major difficulties when sustainability is sought. 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 [7]. Portugal is a large manufacturer of ceramic and also there are many schist mines in this country leading to production of a large amount of wastes from ceramic industry and schist mining. Land filling of such industrial wastes causes also many environmental impacts.

Ceramic waste is recently investigated to be used as a partial replacement of Portland cement in concrete and mortar [8-20] and some researches approved the pozzolanic reactivity of ceramic powder with the Portland cement [8-11]. Torgal showed that concrete with ceramic waste powder although has a minor strength loss possess increase durability performance because of its pozzolanic properties [8]. O'Farrell et al. [12,13,14] studied the effect of waste clay brick on the compressive strength of mortars and found a decrease in early strengths up to 28 days but increase in 90-days strengths and reported increased sulfate resistance, Lavat et al. [15] measured decrease in early strengths, Toledo Filho et al. [16] and Goncalves et al. [17] could observe a slight increase in compressive strengths for the cement replacement by waste brick powder up to 10–20%. They also reported sorptivity decreases with the increasing amount of ground brick. A decrease in water- and water vapor permeability of mortars containing fine ceramics was reported by Silva et al. [18]. Goncalves et al. [17] and Bektas et al. [19] observed a decrease in chloride ion penetration with the increasing amount of ground brick in cement mortars.

Metamorphic rocks such as slate, schist, and etc. are one of the mostly used rock types in building industry and the relevant wastes are considerable accordingly. One recent study shows that the replacement of Portland cement with 15% slate rock waste yielded high pozzolanic reactivity, cost dvantages and environmental benefits as a green material [21]. But there is no specific study on pozzolanic reactivity of other metamorphic stone wastes such as schist.

This research is in the area of using by-products and wastes and SCM in concrete focusing on ceramic waste, schist and metakaolin and striving to find some alternative reactive materials as a partial replacement of PC.

2. EXPERIMENTAL WORK

2.1. Materials

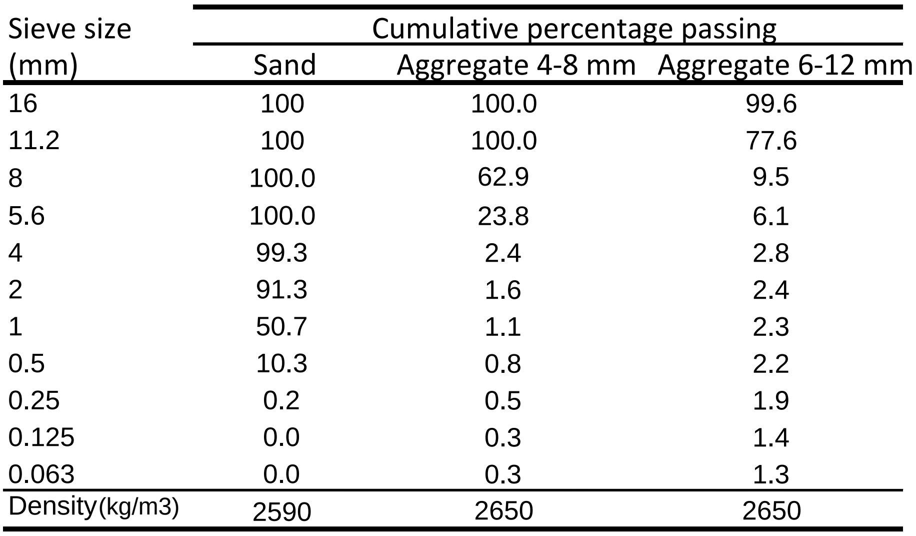
Four types of ceramic waste and three types of slate powder were used in this study; sanitary ceramic (SC), tile ceramic (TC), red roof tile (RRT) and white roof tile (WRT) from different ceramic factories as well as slate powder of mining process of three different slate mines designated here as AS, VS and FCS. The ceramic wastes were ground but the schist slate powders were directly used without additional grinding. Chemical compositions of slates as well as SC are shown in Table 1. Portland cement CEM I 42.5 R was used; the chemical composition of cement is shown in Table 1.

Table 1. Chemical composition

Type	$Si0_2$	Al_20_3	Fe_20_3	$Ca0$	$Mg0$	Na_20	K_20	$Ti0_2$
VS	50.38	26.01	9.83	0.39	2.22	1.26	3.16	1.16
AS	50.63	25.92	9.72	0.53	2.31	1.42	3.3	0.74
FCS	60	20	9			11		
SC	65.8	22.2	0.6	0.1	0.1	1	3.5	0.3
PC	20.15	4.78	3.28	62.2	2.12			

River sand and two types of granite aggregate with gradation and physical characteristics indicated in Table 2 were used.

Table 2. Physical characteristics of Sand/Aggregates



Sieve size (mm)	Cumulative percentage passing		
	Sand	Aggregate 4-8 mm	Aggregate 6-12 mm
16	100	100.0	99.6
11.2	100	100.0	77.6
8	100.0	62.9	9.5
5.6	100.0	23.8	6.1
4	99.3	2.4	2.8
2	91.3	1.6	2.4
1	50.7	1.1	2.3
0.5	10.3	0.8	2.2
0.25	0.2	0.5	1.9
0.125	0.0	0.3	1.4
0.063	0.0	0.3	1.3
Density(kg/m3)	2590	2650	2650

2.2. Test conducted

Experiments were performed in two stages. In the first stage, reactivity of all types of ceramic wastes and slate powders was determined as partial replacement (15%) of Portland cement in mortar and in the second stage, the most reactive ones were selected and used in concrete together with Metakaolin and mechanical properties and durability of mixes were evaluated accordingly.

The mortar used consists of 1 part of binder (85% cement and 15% waste) and 2.75 parts of sand proportioned by mass. Water/binder ratio was 0.485. To have a more precise measure of the reactivity of materials an additional mix, with 85% cement and 15% lime filler, was used as the control mortar mix. Mortars were cast in 50-mm test moulds and compacted by vibrating table in two layers.

The flow values of mortars were determined according to NP EN 1015-3 by measuring the mean diameter of the test samples. The test procedure involves placing the mould (60 mm in height, internal diameter: base 100mm - top 70 mm) on the center of the flow table and filling it in two layers, each layer being tamped ten times with the tamper. Flow values of the mortars are shown in Table 3.

Table 3. Flow value of the mortars

PC	AC	MK	VS	FCS	SC	TC	WRC	PRC
160 mm	130 mm	125 mm	127 mm	155 mm	150mm	156mm	155mm	160 mm

The compressive strength test followed the NP EN 12390-3:2003. The specimens were conditioned at a temperature equal to 18 ± 1 ºC cured one day in the molds and stripped and immersed in lime water until they reached the testing age. Compressive strength for each mixture was obtained from an average of three cubic specimens determined at the age of 3, 7, 14, 28 and 56 days. Results are shown in Figures 1-4.

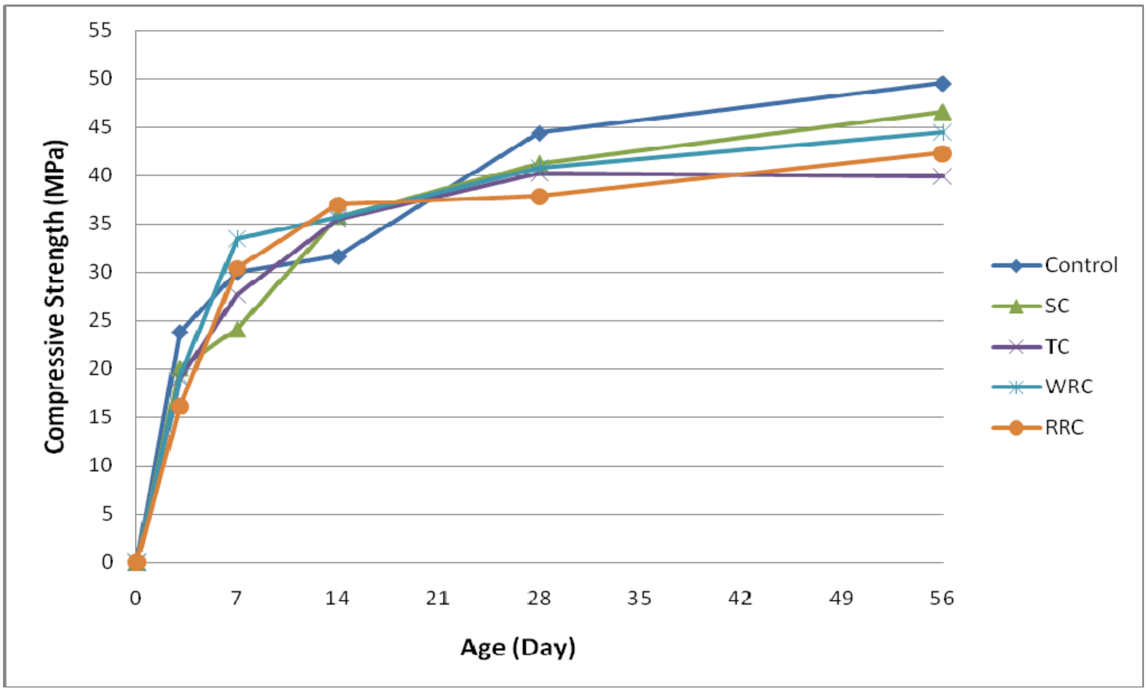


Figure 1. Compressive strength of mortars containing ceramic wastes

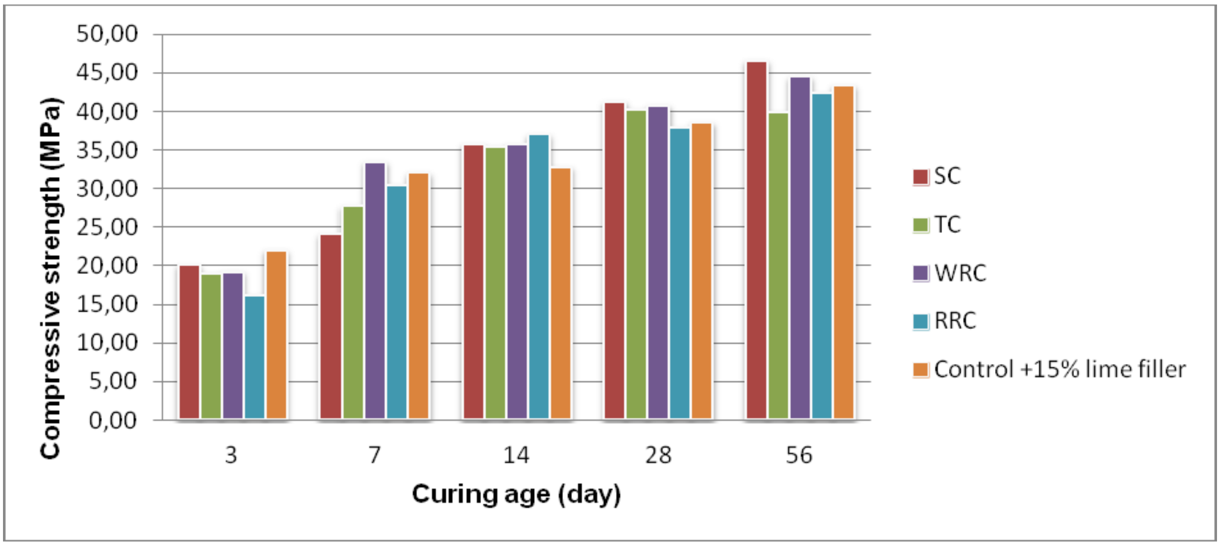


Figure 2. Comparative Strength of ceramic waste types

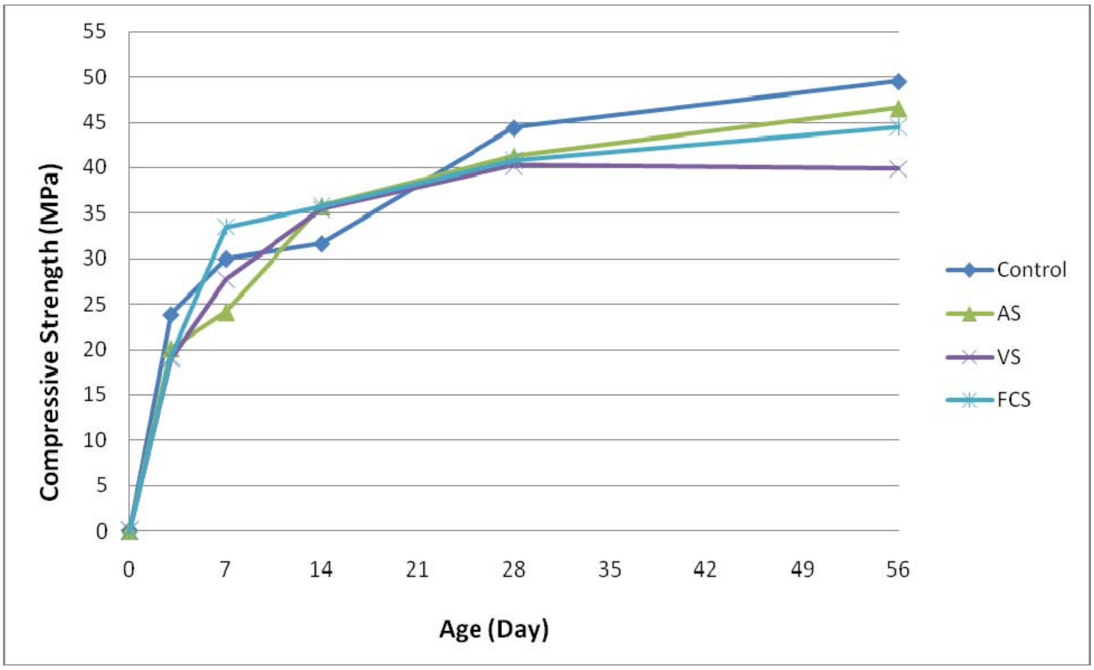


Figure 3. Compressive strength of mortars containing ceramic wastes

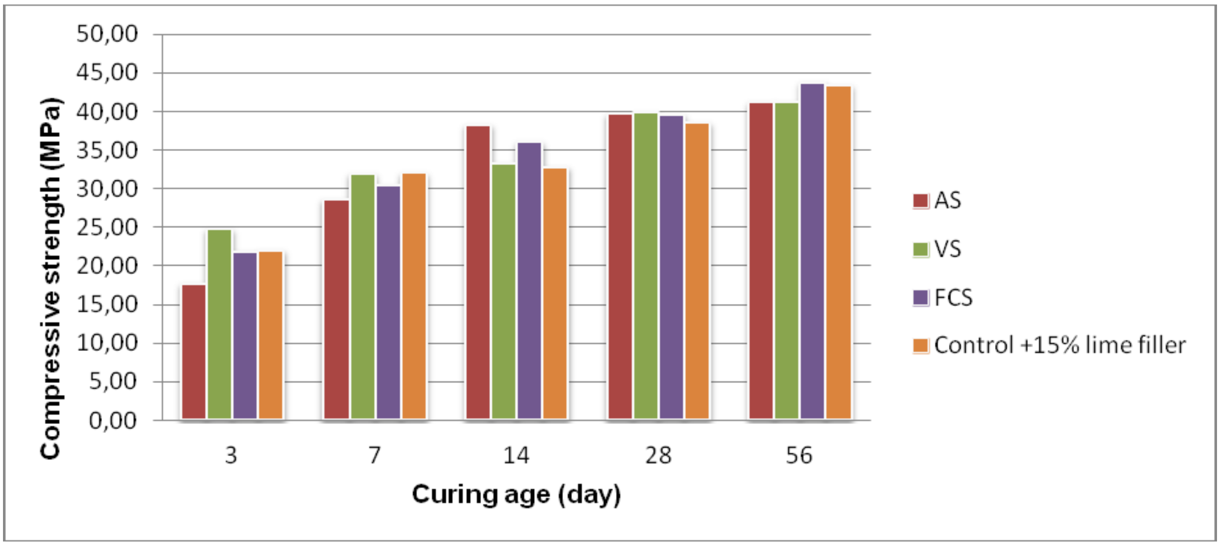


Figure 4. Comparative strength of slate types

Based on results obtained the most reactive ceramic waste (SC) and slate powder (FCS) were selected for the second stage of the experiments. Concrete mixtures were batched using a pan mixer with proportions indicated in Table 4. The amounts of sand and 2 types of aggregate were considered constant in all mixes for 760 kg, 525 Kg and 525 Kg respectively. Cube specimens for compressive strength testing were moulded using 100-mm steel moulds and compacted in two uniform layers using vibrating table. The specimens were cured one day in the moulds and stripped and immersed in lime water until tested. Compressive strength for each mix was obtained from an average of three specimens. Results are shown in Figure 5.

Table 4. Proportions of concrete mixes

Mix	PC (Kg)	MK(Kg)	Water (Kg)	Ceramic(Kg)	Slate(Kg)
Control	400	0	190	0	0
MK10	360	40	190	0	0
MK0-S15	340	0	190	0	60
MK0-C15	340	0	190	60	0
MK10-S15	300	40	190	0	60
MK10-C15	300	40	190	60	0

Durability of mixes was evaluated by measuring the Chloride Ion Migration Coefficient following the norm LNEC E 463. Non-steady-state migration coefficients are calculated by equation (1):

$$Dnssm=\frac{0.0239(273+T)L}{(U-2)t}\left(x_d-0.0238\sqrt{\frac{(273+T)Lx_d}{U-2}}\right) \quad (1)$$

Where:

Dnssm: non-steady-state migration coefficient, ×10–12 m2/s;

U: absolute value of the applied voltage, V;

T: average value of the initial and final temperatures in the anolyte solution, °C;
L: thickness of the specimen, mm;
x_d: average value of the penetration depths, mm*t:* test duration, hour.
Results are shown in the Figure 6.

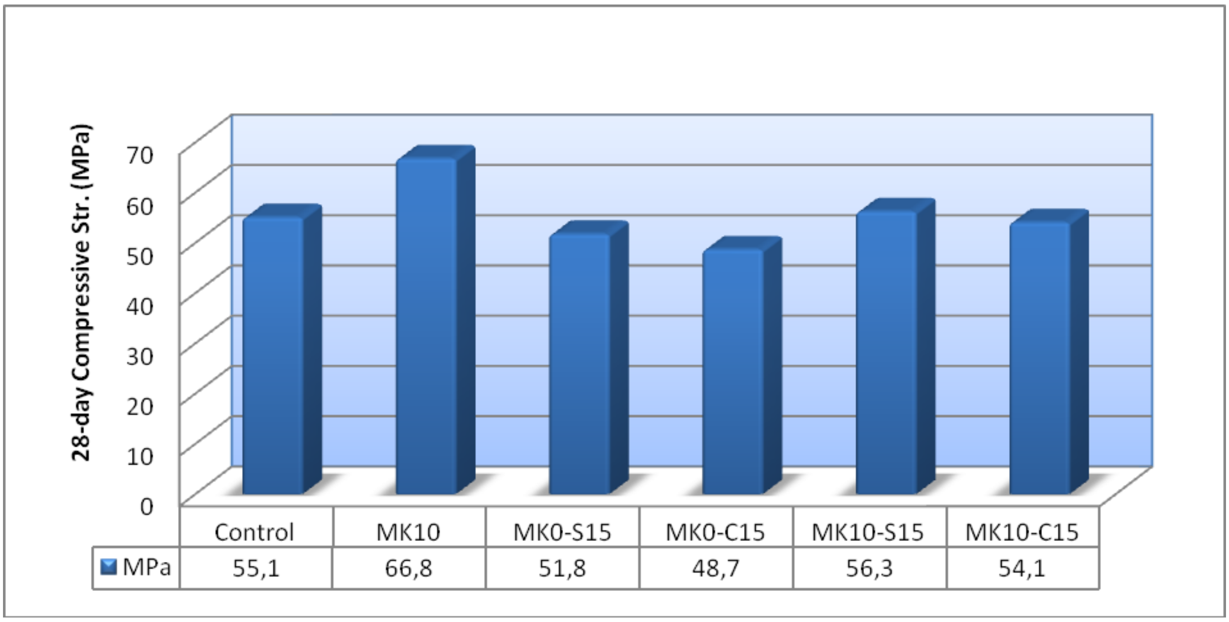


Figure 5. Comparative Compressive Strength

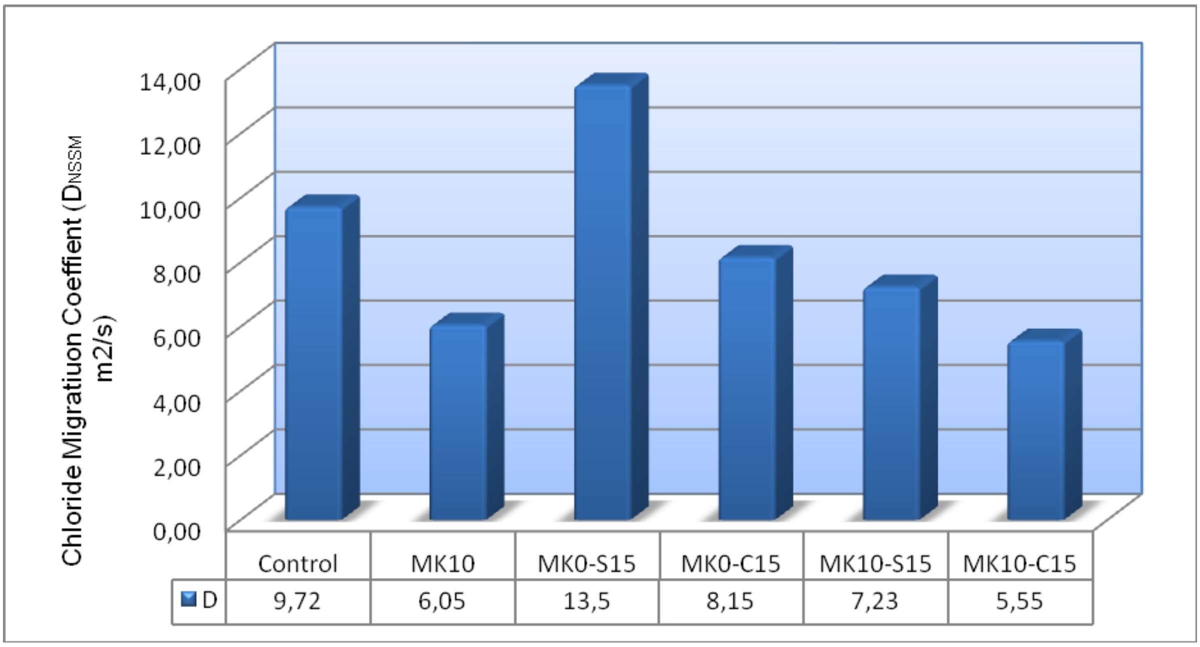


Figure 4. Chloride Migration Coefficient

3. RESULTS AND DISCUSSION

The results of the first stage indicate that all mortars containing ceramic wastes have a lower compressive strength at early ages compared with the control mortar. As curing proceeds, ceramic wastes exhibit higher strengths due to higher amount of reaction products. Sanitary ceramic waste type shows slightly higher pozzolanic reactivity than other ceramic wastes.

All three types of slate powder had similar compressive strength indicating approximately equal reactivity after 28 days curing. At longer curing times, i.e. 56 days, SFC shows higher compressive strength.

Results of the second stage indicate, as expected, that concrete containing 10% of Metakaolin has a high level of compressive strength, i.e. 20% more than control mix, due to high reactivity of metakaolin. While concrete mixes containing 15% ceramic waste and slate powder as PC replacement show a decrease in compressive strength of 6% and 12% respectively. When 15% of ceramic waste or slate powder is used together with 10% of metakaolin a decrease in strength of 16% or 19% compared to mix with 10% metakaolin is observed. This higher strength loss can be attributed to the significantly higher rate of reactivity of metakaolin that leaves less lime available for reaction with ceramic or slate waste. It is interesting to note, however, that similar strength to control mix is achieved with 10% metakaolin and 15% slate or ceramic waste (+2% for slate and -2% for ceramic).

Durability tests show that PC replacement with 10% metakaolin or 15% SC improve the durability of concrete by decreasing the chloride migration coefficient for 38% and 16% respectively compared to control concrete. PC replacement with 15% FCS increases the chloride migration coefficient for 39% compared to control concrete. Concretes with 10% metakaolin and 15% SC or 10% metakaolin and 15% FCS show better durability performance by decreasing the chloride migration coefficient for 43% and 36% respectively compared to control concrete.

Therefore the outcomes of compressive strength and durability test confirm the results of abovementioned studies on using ceramic waste as PC replacement.

One factor that can be proposed for measuring the eco-efficiency of concrete is the weight of PC used in concrete to gain one MPa of compressive strength, Table 5. Bearing in mind that metakaolin is a product and not a waste, we can see that for the mixes with 15% of SC or 15% of FCS,the amount of PC per 1 MPa decreases from 7,3 kg to 6,6 and 7 kg for PC . While for the mixes with 10% MK and 15% SC or 10% MK and 15% FCS the changes are negligible, i.e. 5,3 and 5,5 compared to 5,4 for mix with 10% MK. However, the fact that these wastes are being used and substitute fine sand or other materials is environmentally beneficial. The analysis would be that in terms of PC a reduction of 26% is estimated when MK10 is used while a reduction of 10% and 4% in PC consumption is observed in the case of MK0S15 and MK0C15.

Table 5. Portland cement consumption per unit of compressive strength

Binder	Compressive Str. (MPa)	PC consumption (Kg)	Kg(PC)/Mpa
PC	55,1	400	7,3
MK10	66,8	360	5,4
MK0-S15	51,8	340	6,6
MK0-C15	48,7	340	7,0
MK10-S15	56,3	300	5,3
MK10-C15	54,1	300	5,5

4. CONCLUSIONS

Results reported here are part of an ongoing PhD research work that evaluates the mechanical behavior, durability and environmental effects of using some industrial wastes for partial replacement of cement in concrete. The following conclusions can be drawn from the analysis of results presented:

- As expected the use of MK significantly increases the compressive strength at 28 days. This increase is around 21% which results in a 26% reduction of PC for 1 MPa compressive strength.
- 15% replacement of PC by slate and ceramic wastes results in a decrease of 6% and 12% in compressive strength while at the same time a reduction of 10% and 4% in kg of PC for per MPa of compressive strength is observed.
- The simultaneous use of MK and FCS or MK and SC results in 16% and 19% decrease in compressive strength when compared with MK10. However, in terms of mass of PC per MPa of compressive strength a 1% reduction and 3% increase is estimated.
- Results so far indicate that partial replacement of PC by slate and ceramic wastes lead to a significant reduction in kg of PC/MPa of compressive strength.
- The chloride migration coefficient of concrete with 10% metakaolin, 15% SC, 10% metakaolin and 15% SC, or 10% metakaolin and 15% FCS decreases of 38%, 16%, 43%, and 36% respectively compared to normal concrete.
- Other durability aspects and environmental effects of such applications are under investigation.

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