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A Study of Sustainable Industrial Waste Materials as Partial Replacement of Cement

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Abstract: The recent trends of research in concrete is to produce the eco-friendly cementicious materials by using supplementary materials like cement kiln dust (CKD), ceramic waste, palm oil fuel ash (POFA) and plastic. All of these materials are industrial waste materials and termed as hazardous waste to environment. The aim of this paper is to present the extensive research conducted in this field in a comparative manner to determine the best combination of supplementary material. It was found that the addition of up to 15% CKD as a cement replacement has a negligible effect on the strength of the block. Several concrete mixes possessing a target mean compressive strength of 30 MPa were prepared with 20% cement replacement by ceramic powder (W/B = 0.6). A concrete mix with ceramic sand and granite aggregates were also prepared as well as a concrete mix with natural sand and coarse ceramic aggregates (W/B = 0.5). Results show that concrete with partial cement replacement by ceramic powder although it has minor strength loss possess increase durability performance. Experiments have been conducted by replacing 10%, 20%, 30%, 40% and 50% of POFA by weight of Ordinary Portland Cement. The properties of concrete, such as setting time, compressive strength, and expansion due to magnesium sulfate attack were investigated. The results revealed that the use of POFA in concretes caused delay in both initial and final setting times, depending on the fineness and degree of replacement of POFA. It was observed that adding 5% plastic by weight, the strength was found to be two times greater than the plain cement concrete. With these results it is very clear that we can effectively use these eco-friendly materials to supplement the cement.

Keywords: cement kiln dust, ceramic waste, palm oil fuel ash, plastic.

1. Introduction

As the world population grows, so do the amount and type of wastes being generated. Many wastes produced today will remain in the environment for hundreds and perhaps thousands of years. The creation of non-decaying waste materials, combined with a growing consumer population, has resulted in a waste disposal crisis. One solution to this crisis lies in recycling wastes into useful products. Of all the construction works Concrete is one of the oldest manufactured construction material used in construction of various structures globally until today. K. S. Al-Jabri et.al [1] investigated the properties of hollow sandcrete blocks made with cement kiln dust (CKD) as an additive and as a replacement for ordinary Portland cement. They observed that when CKD was used as a replacement for cement, the compressive strength and density of blocks generally decreased with higher replacement levels of cement by CKD. However, when CKD was used as an additive, within the investigated levels, an improvement in the compressive strength of up to 54% was observed. 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. Fernando and Said [2] suggested that the production of cement requires high energy input (850 kcal per kg of clinker) and the production of one tonne of cement generates 0.55 tonnes of chemical CO_2

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and an additional 0.39 tonnes of CO_2 in fuel emissions, accounting for a total of 0.94 tonnes of CO_2. Therefore, the replacement of cement in concrete by ceramic wastes represents a tremendous saving of energy and has important environmental benefits.

Besides, it will also have a major effect on decreasing concrete costs, since the cost of cement represents more than 45% of the concrete cost. Researchers have studied the use of palm oil fuel ash and revealed that it can be used as a pozzolanic material that contains siliceous or aluminous material by composition [3, 4]. The aim of this research is to utilize the palm oil fuel ash (POFA) as a pozzolanic material in concrete in order to reduce the environmental problems and the landfill area required disposing of POFA.

2. Cement Kiln Dust (CKD):

CKD, also known as cement bypass dust, is a byproduct of the manufacturing of OPC produced by the dry process. It is generated during the calcining process in the kiln. As the raw materials are heated in the kiln, dust particles are produced and then carried out with the exhaust gases at the upper end of the kiln. These gases are cooled and accompanying dust particles are captured by dust collection systems.

2.1. Chemical composition of CKD

Composition of CKD is quite variable from source to source due to raw materials and process variations. The Oman Cement Company generates about 25,000 to 30,000 tons of CKD every year [1]. The product comes out as a fine powder, which is ready to use in cement mixes. Table 1 presents a comparison between the physical properties of ordinary Portland cement and CKD.

Table. 1: Physical Properties of Ordinary Portland Cement and CKD [1]

Test type	Material: Ordinary portland cement	Material: Cement kiln dust
Fineness (cm^2/g)	3,357	4,824
Specific gravity	3.05	2.4
Initial setting (min)	110	150

Table. 2: Chemical Composition of OPC and Palm Oil Fuel Ash [3]

Chemical Constituents	OPC (%)	POFA (%)
Silicon Dioxide (SiO_2)	20.1	55.20
Aluminium Oxide (AL_2O_3)	4.9	4.48
Ferric Oxide (Fe_2O_3)	2.5	5.44
Calcium Oxide (CaO)	65	4.12
Magnesium Oxide (MgO)	3.1	2.25
Sodium Oxide (Na_2O)	0.2	0.1
Potassium Oxide (K_2O)	0.4	2.28
Sulphur Oxide (SO_3)	2.3	2.25
Loss On Ignition (LOI)	2.4	13.86

3. Ceramic Waste:

Ceramic wastes can be separated in two categories in accordance with the source of raw materials. The first one are all fired wastes generated by the structural ceramic factories that use only red pastes to manufacture their products, such as brick, blocks and roof tiles. The second one is all fired waste produced in stoneware ceramic such as wall, floor tiles and sanitary ware. These producers use red and white pastes; nevertheless, the usage of white paste is more frequent and much higher in volume. In each category the fired ceramic waste was classified according to the production process which is shown in Fig. 1.

3.1. Chemical composition

The chemical compositions of ceramic pastes are reported in Table 2. Only the mineralogical composition is modified when these materials are heated. The silica and alumina are the most significant oxides present in the ceramic pastes. It should be noted that the red paste shows high proportion of iron oxide responsible for the red color of the products. Table 3 shows the mineralogical composition of ceramic wastes. As expected quartz and feldspars essentially compose ceramic wastes. For 20% cement replacement represents 3.75 of the cost of Portland cement. This indicates saving of around 17% in the cost of Portland cement in concrete. The cost of cement represents almost 45% of the concrete cost. Therefore, overall cost of concrete will be reduced by more than 7.5%.

4. Palm Oil Fuel Ash (POFA)

Palm oil fuel ash is a by-product produced in palm oil mill. After palm oil is extracted from the palm oil fruit, both palm oil husk and palm oil shell are burned as fuel in the boiler of palm oil mill. Generally, after combustion about 5% palm oil fuel ash by weight of solid wastes is produced [3]. The ash produced varies in tone of color from whitish grey to darker shade based on the carbon content in it.

4.1. Chemical composition of POFA

Both physical properties and chemical analysis indicated that POFA is a pozzolanic material. This pozzolanic material is grouped in between Class C and Class F as specified in ASTMC618-92a. POFA is moderately rich in silica content meanwhile lime content is very low as compared to OPC. However, the chemical composition of POFA can be varied due to operating system in palm oil.

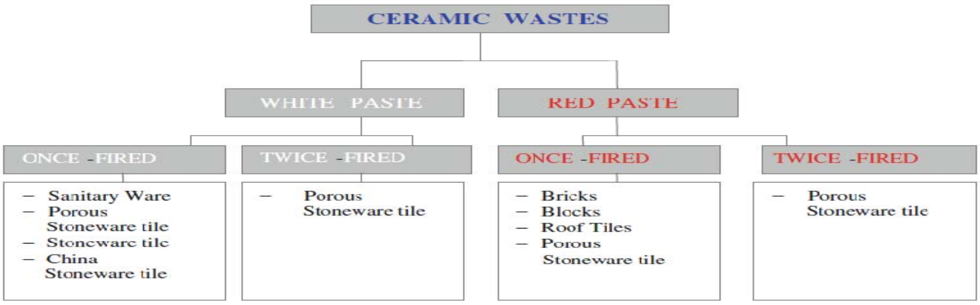

Fig. 1: Classification of ceramic wastes by type and production process [2]

Table. 3: Chemical composition of ceramic pastes (%) [2]

Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	Other
Red paste twice fired ceramic	51.7	18.2	6.1	6.1	2.4	0.2	4.6	0.8	9.9
White paste once-fired ceramic	58.0	18.0	1.0	8.3	0.6	0.2	1.2	0.8	11.9
White paste for twice-fired ceramic	59.8	18.6	1.7	5.5	3.5	1.6	2.5	0.4	6.4
Red paste for stoneware tile	49.1	20.3	7.7	1.2	1.1	0.4	4.2	0.9	15.1
White paste for stoneware tile	65.0	21.3	1.3	0.2	0.3	2.5	3.7	0.2	5.5
White paste for sanitary ware	65.8	22.2	0.6	0.1	0.1	1.0	3.5	0.3	6.4

Table. 4: Mineralogical composition of ceramic wastes [2]

Sample	Majors	Minors	Traces
Ceramic brick	Q	He, C, Ah, Mv, R	Fd
Overheated brick	Q, Fd4	Mv, Cr, Ah, R, He	Lm, G
White roof tile	Q, Mv, Fd4	Ah, He, Cr	G, Hr, Cs, R
Red roof tile	Q, I(Mv)	C, Fd	Ah, He
Ceramic table for cover	Q, Fd	An, He, R	M, E
White porous stoneware tile in double baking	Q	Fd2, Px	Cr, He, R-Cu, G
Red porous stoneware tile in single baking	Q	Zr, He, Fd2	SF, Cr, Mu, Hr, R, Mg
White stoneware tile	Q, Fd4	Cr, ICN, G, Ha	Zr, Mu, He, Ti
Red stoneware tile	Q, Fd1	Cr, Mu, Px	Ah, Zr, He, Mg, Lm
China stoneware tile	Q	Fd1, Cr, Px	Cu, He

Ah anhydrite, *C* calcite, *Co* cordierite, *Cs* celsian, *Cr* cristobalite, *Cu* corundum, *E* esseneite, *Fd* feldspars, *Fd1* albite Ca, ord, *Fd2* anorthite Na, ord, *Fd3* orthoclase, *Fd4* anorthoclase, *G* gehlenite, *Ha* hauyne, *He* hematites, *Hr* hercynite, *I* illite, *Lm* lime, *M* mullite, *Mg* magnetite, *Mv* muscovite, *Px* piroxene, *Q* quarz, *SF* franklinite, *Ti* titanite, *Zr* zircon

5. Plastic

A material that contains one or more organic polymers of large molecular weight, solid in its finished state and at some state while manufacturing or processing into finished articles, can be shaped by its flow, is termed as "**Plastics**".

5.1. Sources of generation of waste plastics:

Household: Carry bags, bottles, containers and trash bags.

Health and Medicare: Disposable syringes, glucose bottles, blood, Intravenous tubes, catheters and surgical gloves.

Hotel and Catering: Packaging items, Mineral water bottles, Plastic plates, Glass etc.

5.2. Advantages of using plastics in concrete:

The growth in the use of plastic is due to its beneficial properties, which include:

Lighter weight than competing materials reducing fuel consumption during transportation.
Resistance to chemicals, water and impact.
Excellent thermal and electrical insulation properties.
Unique ability to combine with other materials like aluminum foil, paper, adhesives.
Intelligent features, smart materials and smart systems.
Reduction of municipal solid wastes being land filled.

5.3. Disadvantages of plastics:

The followings are the main disadvantages of using the plastics in concrete are as follows:

Plastics are having low bonding properties so that the strength of concrete gets reduced such as compressive, tensile and flexural strength.

Its melting point is low so that it cannot be used in furnaces because it gets melt as its comes in contact with the heat at high temperature.

6. Compressive Strength as Compared to Different Materials:

6.1 Cement kiln dust

To investigate the potential use of CKD in the production of normal weight concrete blocks, concrete specimens were prepared using different proportions of CKD ranging from 0 to 15% as a partial substitute for Portland cement. The work was conducted using block manufacturing facilities at the Oriental Company. From each mix, five block samples were tested in compression at 7, 14, 21, and 28 days of curing. Compressive testing of the blocks was done in accordance with OS1 (OS 1977) [1]. Each block was first dried, weighed, and placed between the platens of a Dartec compression machine. Results were compared with the Omani specifications for the production of precast concrete blocks (OS1) (OS 1977), and are shown in Table 5

Table. 5: Compressive Strength of Blocks and Masonry Column at Different Proportions of CKD as a Cement Replacement [1]

Cement kiln dust (%)	Average compressive strength of block (MPa)				Average 28-day column compressive strength (MPa)
	7 days	14 days	21 days	28 days	
0	—	—	—	10.4	10
5	8.5	10.8	—	14.8	15
7	8.4	9.6	—	12.7	12.7
9	8.8	11.2	—	13.1	14.6
11	11	12	12.1	11.9	12.7
13	10	9.7	11.4	11.7	—
15	5.9	7	9.6	10.1	—

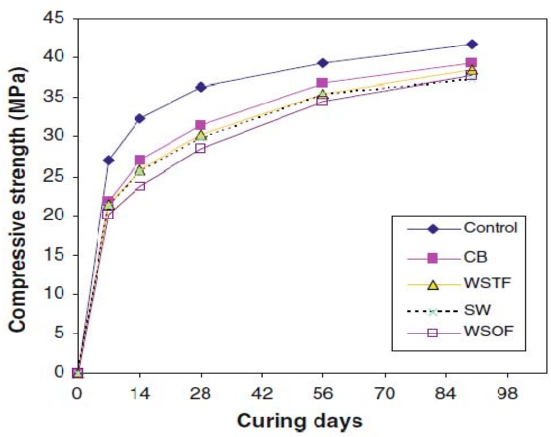

Fig. 2: Compressive strength of concretes with ceramic powder at different curing ages [2]

6.2. Ceramic waste

The compressive strength was determined following the NP EN 12390-3 [2]. The specimens were cured under water at a temperature equal to 18 ± 1_C until they have reached the testing ages. Tests were performed on 100 9 100 9 100 mm3 specimens. Compressive strength for each mixture was obtained from an average of three cubic specimens determined at the age of 7, 14, 28, 56 and 90 days of curing.

6.3. Palm oil fuel ash

It is mentioned earlier that the test specimens were cast with OPC and OPC with POFA added at various percentage replacement level. Here, all the specimens were tested for compression at the age of 7 and 28 days. Generally, Table 3 and Fig.1 reveal that increase in the level of POFA replacement lead to the reduction of compressive strength in aerated concrete. Besides that, it can be observed that replacement of POFA 10 to 40% exhibit significant development in strength of aerated concrete from 7 days to 28 days.

6.4. Plastic

Yadav et al. [5] studied the effects of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the compressive strength of concrete. It is found that compressive strength of concrete mixtures decreased with the increase in PET aggregates and for a particular PET aggregate content, compressive strength increased with the reduction in w/cm ratio.

Table. 6: Compressive strength Performance Of aerated Concrete Without and With Various Level of POFA Replacement at 7 and 28 days [3]

% POFA Replacement	OPC Aerated Concrete Strength (MPa)	
	7days	28 days
0	5.49	7.70
10	4.89	6.10
20	3.16	5.84
30	2.54	3.81
40	0.83	1.95
50	0.63	0.96

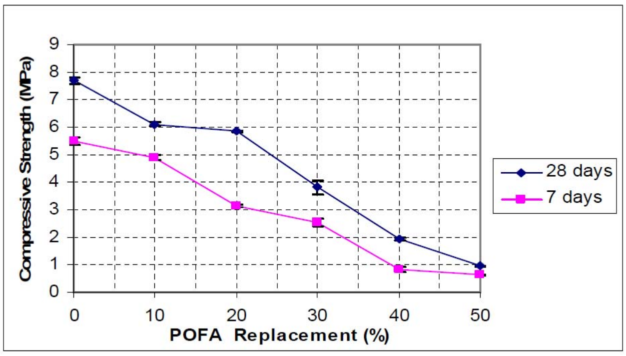

Fig. 3: Effect of POFA Content on Compressive Strength of Aerated Concrete at 7 and 28 days [3]

Table. 7: Compressive strength of Hardened concrete

w/cm ratio	PET aggregate (%)	Compressive strength (MPa)		
		3 days	7 days	28 days
53	0	18.4	24.0	3.27
	25	17.6	23.4	2.65
	50	17.1	21.5	2.25
	75	14.8	19.2	2.04
49	0	19.0	27.8	3.27
	25	18.8	26.7	2.76
	50	18.6	24.3	2.35
	75	15.8	21.6	1.94
45	0	24.8	31.3	3.32
	25	23.2	27.4	2.80
	50	22.0	26.5	2.55
	75	20.7	24.8	2.04

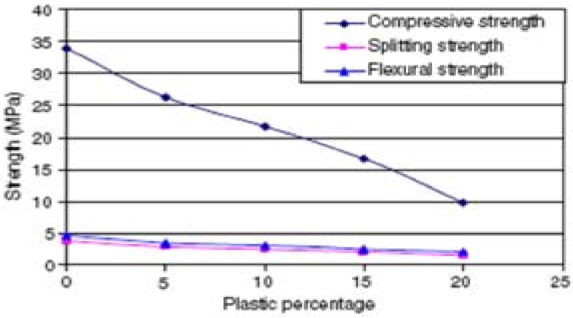

Fig. 4: Relationship between the compressive strength and percentage of plastic content

7. Conclusions

Cement kiln dust used as a partial replacement for cement showed that the addition of up to 15% CKD as a cement replacement gave a comparable 28-day compressive strength to the ordinary normal weight concrete blocks widely used in construction.

Using ceramic wastes in concrete can solve several environmental problems and has minor strength loss which dependent on the pozzolanic reactivity of the different ceramic wastes.

Success in incorporating certain percentage of POFA as partial cement replacement that either produce POFA aerated concrete having same strength as ordinary aerated concrete or higher strength than existing aerated concrete definitely will reduce cement consumption in their construction work.

Plastics can replace aggregates which are lighter in weight, resistance to freeze and thaw, reduce the thickness of pavements and withstand fatigue.

8. References

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