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Study the Effect of Using Ceramic Waste Powder as Partial Replacement for Cement on Concrete Properties

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Abstract

Ceramic waste is one of the most active research areas that encompass a number of disciplines including civil engineering and construction materials. Ceramic waste powder is settled by sedimentation and then dumped away which leads to environmental pollution, in addition to forming dust in summer and threatening both agriculture and public health. Therefore, utilization of the ceramic waste powder in various industrial sectors especially the construction, agriculture, glass and paper industries would help to protect the environment. It is most essential to develop eco-friendly concrete from ceramic waste. In this research replacing the (OPC) cement by ceramic waste powder has been studied accordingly in the range of (0, 10, 15, and 20) % by weight of M-30 grade concrete. Concrete mixtures were produced, tested and compared in terms of compressive and tensile strength to the conventional mixture. These tests were carried out to evaluate the mechanical properties for 7 and 28 days. As a result, the CWP cement concretes decreased the workability retention. The values of average hardened concrete density for concrete mixes with CWP cement are higher than the reference mix in 7 days, but lower than the reference mix in 28 days. The maximum value of compressive strengths at 7 and 28 days and tensile strength was achieved at about 5% CWP concrete mix. CWP slowed the compressive strength development especially at early ages. All mixtures with CWP showed good strength development at 28 days. It was observed that all CWP replacement ratios achieved higher compressive strength than characteristic compressive strength which is equal to 30 N/mm² in 28 days, except the 20% ratio gives 29.72 N/mm². Test results showed that CWP has potential to be used as an ingredient in concrete mixtures to partially replacing cement. The study showed that concrete mixtures with ceramic waste powder (CWP) had variable performance of the measured properties depending on the replacement level used.

I. INTRODUCTION

This research analyzed the impact of the use of white ceramic powder, gained either as residue from the ceramics industry on the mechanical properties of traditional concrete [10]. Some of the concrete types need high amounts of cement and consequently several disadvantages can be encountered such as potential of high hydration heat, risk of quick setting, shrinkage and high cost etc. [30] In addition to that one of the big problems of cement production is high carbon emission during raw material collecting and production of cement [22]. Cement is the primary and most expensive component of concrete mixture. Partial or full replacement of cement is considered a possible solution toward decreasing the environmental impact of cement production and will also contribute to sustainable concrete [17]. Recently, multiple studies have been completed in different laboratories in an attempt to find alternative raw materials can be used instead of cement. Use of some natural and/or artificial pozzolans and minerals such as fly ash [21], [5], ground granulated blast furnace slag [31], silica fume [9], calcite [31], metakaolin [18], diatomite [29], brick powder [35], and waste marble dust [19] are widely estimated for use them in the production of different types of concretes [30].

In 2015, ceramic tile production at global level was around 12.4 million square metres [4], [13], of which 1030% is discarded as waste [25]. Additionally, the greatest proportion of this waste is non-recyclable, which is highly problematic in terms of disposal [12]. Senthamarai and Manoharan (2005)

have indicated that 30 % of daily production of ceramic industry goes to waste [32]. At present, ceramic wastes are mostly not recyclable and, so, these materials report to landfill [3]. Its deposition into landfills challenges the environment [25], [15].

However, the ceramic waste powder (CWP) is durable, hard and highly resistant to biological, chemical, and physical degradation forces. The Ceramic industries are dumping the powder in any nearby pit or vacant spaces, this leads to serious environmental and dust pollution and occupation of a vast area of land, especially after the powder dries up so it is necessary to dispose the CWP quickly and use in the construction industry. As the ceramic waste is piling up every day, there is a pressure on ceramic industries to find a solution for its disposal. The advancement of concrete technology can reduce the consuming of natural resources [27]. However, it is interesting that some experimental studies have indicated that CWP are adequate as partial replacement for cement and natural aggregates [32], [3], [2]. Therefore, the replacement of cement in concrete by CWP 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 [2]. Several authors already confirmed the pozzolanic reactivity of ceramic wastes [20], [23]. Nevertheless, research carried out so far by reusing ceramic wastes in concrete. Consequently the aim of this research project is the assessment of the mechanical and durability properties of ceramic waste based concrete.

II. PREVIOUS STUDIES

Several researchers have investigated the effects of using ceramic wastes (i.e., roof tiles, blocks, bricks, electrical insulators, etc.) as aggregates in concrete mixtures. The use of ceramic sanitary ware waste as coarse and fine concrete aggregates was investigated and it was concluded that ceramic waste aggregates are feasible to be used in concrete manufacture [8]. Amel et al. [1], replaced cement with ceramic waste powder at different percentage of composition (5, 10, 20, and 30) % they were tested after 28 days for compression strength, we conclude that ceramic wastes are suitable to be used as substitution for cement production They were found to be performing better than normal concrete, in properties such as slump is reduced with increasing the ratio of ceramic powder, weight of cubes decreases when increasing the ratio of ceramic powder and at 10% replacement burned at 7500 compressive strength increased by 8.9% from the standard mix, Ceramic waste powder is suitable for use in concrete industry by 10% replacement of cement content. Previous research [27] showed the use of CWP replaced cement accordingly in the range of (0, 10, 20, 30, 40, and 50) % by weight of M-20 grade concrete. Concrete mixtures were produced, tested and compared in terms of compressive strength to the conventional concrete. These tests were carried out to evaluate the mechanical properties for 7, 14 and 28 days. Test results showed that the Compressive Strength of M20 grade Concrete was increased when the replacement of Cement with Ceramic Powder up to 30% replaced by weight of Cement and further replacement of cement with Ceramic Powder of high percentages decreased the Compressive Strength.

Yun-hong Cheng et al. [7] used CWP as partial replacement for cement at different percentage of composition (10, 20, 30, and 40) % and found that the consistence of concrete does not change because of addition of CWP; the permeability resistance of the concrete mixed with waste ceramic polishing powder is superior to that of the control group. Particularly, the permeability resistance of concrete is the best when 30 % of cement is substituted by waste ceramic polishing powder. Local studies [34] have concluded that the CWP can be considered reasonable alternative source of cement at different percentage of composition (10, 20, 40, and 60) % by mass for concrete mixture production and it was concluded that the bulk density of analyzed HPC mixes decreased with the increasing amount of fine ground ceramics in the mix and the open porosity increased in a corresponding way. This indicated possible problems with both mechanical properties and durability for mixes with higher Portland cement replacement, inclusion of more than 20% ceramic waste reduced the compressive strength while durability characteristics were satisfactory, the frost resistance of all studied concrete mixes was excellent. They also exhibited good chemical resistance in all environments Up to 40% replacement level the mixes with fine ground ceramics performed even better than the reference mix. Shraddha et al. [26] in this research ceramic waste powder from ceramic wall tiles industry is used as replacement to cement in concrete in an incremental order like 0%, 10%, 20%, 30%, 40%, 50% and 60% by weight of

cement in concrete for M 25 grade. It was showed that when Sodium silicate used as binder with cement, the setting time of cement get affected, It was observed that the workability was reduced by increasing the amount of the CWP in the concrete, and the Compressive Strength of Concrete was decreased in all mixes when the replacement of Cement with Ceramic Powder, and when observing the cost of concrete at this point is reduced up to 16.3% in M25 grade of concrete and becomes economical with compromising the target strength of concrete. Pavel Reiterman et al. [28] showed that when It's been using CWP replaced cement accordingly in the range of (0, 20, 40, 60, 80, 100, and 120) % , and from the presented results is evident influence of fine ceramic powder on the number of properties of concrete, where it was used as active admixture. The mechanical properties are deteriorated with increasing replacement of CWP but reduction of compressive strength is around 15% in mixture with maximum studied dosage. At dosages of more common in practice, therefore, about 10% by weight of cement is then the total reduction in the mechanical properties of about 3%, a result comparable to the use of e.g. fly ash and other pozzolanic admixtures. Reduction of mechanical properties is closely related with the bulk density, which logically gets low with increasing amount of CWP, because it has a lower bulk density than used Portland cement. Presented results perform good potential of fine ceramic powder for using as an active additive to concrete. General properties of studied concrete mixtures confirm rate of competitiveness with other pozzolanic additives. Kanaan and ELDieb [16], Results of the experiments which are carried out on hardened concrete, indicated that using of (10, 20, 30, and 40) % as a replacement percentage of the CWP to the cement, the fresh concrete properties for the 25 MPa mixtures showed that the use of ceramic waste powder in concrete mixtures improved its workability retention and Hardened concrete properties of 25 MPa concrete mixtures included CWP exhibited an overall strength improvement all ages except for 7 days of age. The use of 10 % CWP resulted in the highest strength improvement. With CWP replacement levels above 10% the strength improvement was lower. The development of compressive strength could be accredited to the micro filling ability and the pozzolanic reactivity of the CWP material. All HPC mixtures, M 75, with CWP above 10% replacement level showed reduction in the strength values at all ages. Pacheco and Jalali [25], Results showed that concrete with CWP although has a minor strength loss possess increased durability performance because of its pozzolanic properties. Results also showed that replacement of traditional sand by ceramic sand is a good option because it does not imply strength loss and has a superior durability performance. As for the replacement of traditional coarse aggregates by ceramic coarse aggregates, the results are promising but underperformed slightly in water absorption and in water permeability meaning that the replacement of traditional sand by ceramic sand is a better option. Heidari and Tavakoli [11], this study have indicated that recycling of the CWP as cement in concrete proved to be an economical and environmentally friendly solution and due to appropriate physical and mechanical characteristics. The different percentage of composition (10, 20, 30 and 40)%

for concrete mixture production and it was concluded that when adding ground ceramic up to 20% does not have a significantly negative effect on the compressive strength of concrete. Furthermore, using any amount of ground ceramic in the concrete reduces its water absorption capacity. Previous research [27] showed that the use of the CWP replaced cement accordingly in the range of (10, 20, 30, and 40) % by mass. Test results showed that CWP has potential to be used as an ingredient in concrete mixtures to partially replace cement. The study showed that concrete mixtures with ceramic waste powder (CWP) had variable performance of the measured properties depending on the replacement level used. In general, CWP can be used in concrete mixtures to partially replace cement and improve specific performance criteria a 10% to 20% CWP was suitable for optimizing the workability retention and strength of the mixture. However, the use of 30% to 40% CWP would optimize the combination of all studied criteria. Kannan et al. [17], results of the experiments which are carried out on hardened concrete, indicated that using of (10, 20, 30, and 40) % by mass as a replacement percentage of the CWP to the cement achieved the highest values of compressive strength in mixes.

Local studies [13], [12], [32], have concluded that the CWP can be considered reasonable alternative source of cement for concrete asphalt mixture production. Fernando et al. [24], utilized two ceramic waste types from different sources as cement replacement. The study concluded that ceramic waste has pozzolanic activity which contributed to the concrete performance. Also, Steiner et al. [33] studied the pozzolanic activity of ceramic tile polishing residues and concluded that the material achieved a pozzolanic activity index of 111%. The compressive strength at 120 days of curing was 41.5 MPa when using 25% Mix PR. Other studies investigated the use of CWP [24], [16], [11], [14], [36] concluded that CWP had no pozzolanic activity at early ages while displayed pozzolanic activity at late ages. All studies concluded that the inclusion of CWP affected early strength and that the strength development needed more time than control mixtures without CWP. Accordingly, a number of researches have focused mainly on the use of CWP as cement replacement [7], [6], they concluded that CWP was beneficial in reducing permeability and improving the measured durability aspects. Although there are studies on the use of CWP as cement replacement in concrete, the effect of CWP on fresh concrete, split-cylinder tensile and flexural strengths was not addressed. Also, the studies showed that the effect of CWP on strength and durability was variable depending on the mixture and the CWP replacement level. There were no guidelines on the use of CWP as partial cement replacement in concrete mixture. The selection of the CWP replacement level to optimize concrete performance will depend on personnel knowledge and experience of the material. Therefore, the development of a method to select CWP replacement is highly needed and necessary such that practitioners can easily select the CWP replacement level needed for a required performance.

III. RESEARCH OBJECTIVE

The main aim of this research is to reuse the waste of ceramic processing on concrete as cement to provide their landfilling and to investigate the effects of mechanical properties of concrete containing ceramic waste powder (CWP) as partial replacement of cement, consequently the objectives from this research can be as the following:

- 1) Studying the possibility of using the Ceramic Waste Powder by replacing ordinary Portland cement in 5, 10, 15, and 20 %.
- 2) Measure the workability of concrete by measuring the slump of the mixtures.
- 3) Measure the compressive strength of the hardened concrete.
- 4) Measure the split-cylinder tensile.

IV. MATERIALS AND METHODS

A. Materials

1) *Cement*: Cement, in the general sense of the word, can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragments into a compact whole. The cement was used in this study for casting all specimens is Ordinary Portland Cement produced by Misr Cement (Qena) Co. Grade 42.5 conforming to BS EN 197-1:2000. Its physical properties are listed in TABLE I.

2) *Ceramic Waste Powder (CWP)*: CWP cement was obtained from Ras Al Khaimah Ceramic's factory. CWP is shown in figure (1), a chemical analysis of the CWP was done, the chemical composition of the CWP was compared with the chemical composition of the cement material, and the results were in the same level. The chemical composition is listed in TABLE II.

Fig. 1. Ceramic Waste Powder Sample

TABLE I
PHYSICAL PROPERTIES OF CEMENT.

Properties	Values
Consistency	33.50%
Initial setting time	140 min
Final setting time	245 min
7 days strength	42.31 N/ mm ²
Soundness	2 mm

TABLE II
CWP CHEMICAL COMPOSITION.

Element	Result %
SiO ₂	60.5
AL ₂ O ₃	7.2
CaO	7.1
MgO	2.1
K ₂ O	4.4
Fe ₂ O ₃	3.8

3) *Fine Aggregate (FA)*: The sand used in this study for casting all specimens was locally river sand. Specific gravity was (2.5) according to BS EN 1097-6:2000. Sieve analysis was investigated as per BS EN 933-1 and particle size distribution was within the limits requirement that have been given in BS 882 (1992). Particle size distribution shown in Fig. 2.

Fig. 2. Particle Size Distribution of FA

4) *Coarse Aggregate (CA)*: A locally rounded natural aggregate was used with 20 mm maximum size. Specific gravity and Unit weight were (2.63, 1668.43 Kg/m³) according to BS EN 1097-6:2000. Sieve analysis was investigated as per BS EN 933-1 and particle size distribution shown in Fig. 3. Particle size distribution was within the limits requirement that have been given in BS 882 (1992).

B. Mix Proportion

Five concrete mixes were prepared, one of which was a reference concrete mix made using ordinary Portland cement (OPC) without adding CWP cement, and the other four mixes were made by replacing the cement by (5,10,15, and 20) % ceramic waste powder as shown in TABLE III, IV for cubes and cylinders.

Fig. 3. Particle Size Distribution of CA

Fig. 4. Slump test results

V. RESULTS AND DISCUSSIONS

A. Slump

As can be seen Fig. 4, The CWP mixture shows relatively lower slump comparing with the reference mix, the addition of the CWP cement decreases the slump.

TABLE III
MIXTURES PROPORTION OF CONCRETE FOR CUBES (KG/M³)

Mix	Cement	CWP	Water	FA	CA
0%	9.6	-	4.6	14.9	27.5
5%	9.12	0.48	4.6	14.9	27.5
10%	8.64	0.96	4.6	14.9	27.5
15%	8.16	1.44	4.6	14.9	27.5
20%	7.68	1.92	4.6	14.9	27.5

TABLE IV
MIXTURES PROPORTION OF CONCRETE FOR CYLINDERS (KG/M³)

Mix	Cement	CWP	Water	FA	CA
0%	8.6	-	4.14	13.4	24.7
5%	8.17	0.43	4.14	13.4	24.7
10%	7.74	0.86	4.14	13.4	24.7
15%	7.31	1.29	4.14	13.4	24.7
20%	6.88	1.72	4.14	13.4	24.7

Fig. 5. Relation between percentage of CWP and Average Density of concrete at ages of 7 and 28 days for cubes.

Fig. 6. Relation between percentage of CWP and Average Density of concrete at ages of 28 days for cylinders.

B. Density

Fig. 5, 6 shows the values of average hardened concrete density, density of concrete mixes with CWP cement is higher than the reference mix in 7 days, but in 28 days is lower than the reference mix.

C. Compressive Strength

The compressive strength was measured at 7 and 28 days and the results were discussed as follows:

1) 7, 28 days Compressive Strength: The compressive strength at 7 days after curing of mixes with five different percentages of adding CWP cement is Fig. 7. It can be seen that the compressive strength of CWP concrete mixes are lower than the reference mix.

Fig. 7. 7, 28 days compressive strength

Fig. 8. Failure surface of cube

D. Split Tensile Strength

The split-cylinder tensile strength was measured at 28 days and the results were discussed as follows: The split-cylinder tensile strength 28 days after curing is shown in Fig. 9. The trend of the tensile strength development was approximately similar to that of the compressive strength development. The split-cylinder tensile strength of CWP concrete mixes are lower than the reference mix.

Fig. 9. 28 days split tensile strength

Fig. 10. Failure surface of cylinder

VI. CONCLUSIONS

This study aimed to investigate the potential of using ceramic waste powder (CWP), produced during the final polishing process of ceramic tiles, as an alternative ingredient to partially replace cement in concrete mixtures. The study focused on identifying the different characteristics of the CWP. Also, performance of different concrete mixtures including CWP as partial replacement of cement (i.e., 5%, 10%, 15% and 20% by weight) was evaluated. The fresh concrete was evaluated by its workability retention. Hardened concrete was evaluated by measuring compressive strength development and split tensile strength. The following main conclusions are based on the obtained results:

- CWP particles are similar to those of cement in shape and included more than 60.5 SiO_2 . The characteristics of CWP show that the material has potentials to be used as an alternative ingredient to partially replace cement to produce sustainable and economical mixtures.
- Results of the experiments carried out on fresh concrete; indicate that the CWP cement concretes decrease the workability retention.
- Results of the experiments carried out on hardened concrete; indicate that the values of average hardened concrete density for concrete mixes with CWP cement are higher than the reference mix in 7 days, but lower than the reference mix in 28 days.
- Results of the experiments carried out on hardened concrete; indicate that the maximum value of compressive and tensile strengths at 7 and 28 days was achieved at about 5% CWP concrete mix.
- CWP slowed the compressive strength development especially at early ages. All mixtures with CWP showed good strength development at 28 days of age.
- It was observed that all CWP replacement ratios achieved higher compressive strength than characteristic compressive strength which is equal to 30 N/mm² in 28 days, except the 20% ratio gives 29.72 N/mm².
- Concrete on 20% replacement of Cement with Ceramic Powder, Compressive Strength obtained is 29.72 N/mm² and vice-versa the cost of the cement is reduced up to 20% in M30 grade and hence it becomes more economical without compromising concrete strength than the standard concrete. It becomes technically and economically feasible and viable.
- Recycling ceramic waste powder as cement in concrete not only improves mechanical properties of concrete, but also helps the surrounding environment to be protected against its severe deposit problems and avoiding their landfilling.

It is the possible alternative solution of safe disposal of ceramic waste.

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