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USING CERAMIC WASTES IN CONCRETE MANUFACTURING FOR SUSTAINABLE CONSTRUCTION MATERIALS AS COARSE AGGREGATE REPLACEMENT

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About 30% of the ceramic production all over the world considered as waste. This huge amount of ceramic waste can be recycled in the construction industry, especially in concrete mix design, which is the main scope of this research. Ceramic wastes could provide many advantages rather than sustainability. It is considered economical and can replace cement, coarse aggregate, and fine aggregate, such as sand. In this study, several concrete mixtures were designed according to the ACI standards to assess the ceramic waste concrete for fresh and hardened properties in terms of slump, concrete compressive, splitting tensile and flexural strengths. Six mixes included with 0%, 10%, 20%, 30%, 40% and 50% replacement of coarse aggregate by crushed ceramic waste. By comparing the results between ceramic waste concrete and conventional concrete specimens, the optimum mix design was found to be at 30%-coarse aggregate replacement. Scanning electron microscope tests performed on the concrete specimens to examine the bond between the particles, the porosity, and the elementary composition of the specimens. The percentage of savings in cost estimated when using the optimum mix design (30% coarse aggregate replacement) was about a 30% reduction in the construction cost per the Egyptian market.

Keywords: Mechanical properties, SEM, Cost analysis, Recycle.

1 INTRODUCTION

Concrete is the most used human-made product all over the world. Six billion tons of concrete produced per year consumes about fourteen billion tons of the strategic materials (cement, sand, and coarse aggregate) (Raval *et al.* 2013). About thirty percent of the ceramic industry comes out as waste. This massive amount of wastes received by landfills receives, which consumes space, cost, and have a high environmental impact (Senthamarai and Manoharan 2005). The disposal of construction wastes requires special techniques and has a high environmental impact as opposed to the recycling of these construction wastes in the concrete mix industry.

In most cases, the disposal of construction waste occurs using odd methods, for instance, throwing the wastes on road shoulders or desserts. The disposal method depends on the culture and the awareness of the involved parties of the construction industry. Therefore, using ceramic waste as a replacement of the strategic materials is an important issue to address as it decreases the demand while using the construction waste, especially ceramic, which has a negative environmental impact.

2 RESEARCH OBJECTIVES AND METHODOLOGY

The construction wastes include glass, ceramic, marble, bricks, hardened mortar, and concrete. Recycling these materials in construction rather than placing them in landfills save a limited place. However, the question raised about the applicability of using the ceramic waste to replace any of the concrete mixture ingredients. This research investigates the use of ceramic waste as a replacement for coarse aggregate. The main objective is to reach the optimum percentage for replacing the average coarse aggregate with the ceramic waste in the concrete mixtures as a function of the optimum mechanical properties resulted. Furthermore, the research explores the cost reduction that might result from using ceramic waste through the Egyptian market. Kavitha and Sundar (2017) stated that the use of ceramic as a coarse aggregate replacement protects the environment and avoid the high usage rate of the strategic preserved materials such as the natural aggregate.

An experimental program consists of six mixes designed and prepared to evaluate the mechanical properties in terms of compressive, splitting tensile and flexural strengths, in addition to the physical properties presented in the density of concrete and the slump representing the plastic state of concrete. Hence, for each concrete mix, concrete cube, cylinder, and prism specimen are prepared. The specimen dimensioned 15 x 15 x 15 cm for cubes, 10 cm in width x 10 cm in depth and 50 cm in length for prisms, finally; 15 cm in diameter and 30 cm in height for splitting cylinders (ECP 207 2018). For each mix, there are two groups according to the age of testing; at 7 and 28 days curing. Therefore, at each age, two groups consisted of 3 cube, three-cylinder, and three prism specimens.

All physical and mechanical properties test required for coarse, fine aggregate, and ceramic used as a coarse aggregate replacement evaluated to encounter during mix design. The constant mix design parameters used to create the concrete mix provided in Table 1. The specific gravity of cement and the fine and coarse aggregate was 3.15, 2.6, and 2.65, respectively. The absorption percentage and moisture contents were 1% for coarse aggregate and 0.12% for fine aggregate. Moreover, the fineness modulus of the fine aggregate was equal to 2.6. Figure 1 and Table 1 show the sieve analysis of ceramic compared to the natural coarse aggregate and the physical properties assessed through the aforementioned performed tests.

Table 1. Concrete mix design constant parameters.

W/C ratio	0.48
Exposure Factor	0.5
Water Content, (kg/m^3)	190
Cement Content, (kg/m^3)	396
The volume of CA, (m^3)	0.64
Weight of CA, (kg/m^3)	1002.88
Total weight of Concrete, (kg/m^3)	2355
Weight of FA, (kg/m^3)	766

Table 2. Physical properties evaluated through the tested mentioned above according to ECP 203 (2018) and ASTM C128 (2015) and ASTM C535 (2016).

	Coarse aggregate	Fine Aggregate	Ceramic
Density (Kg/m^3)	1530	1193.3	1746.7
Abrasion (LOS ANGELES)	25.3	37.4	NA
Absorption	2.581	NA	14
Specific Gravity	2.5	2.5	3.03

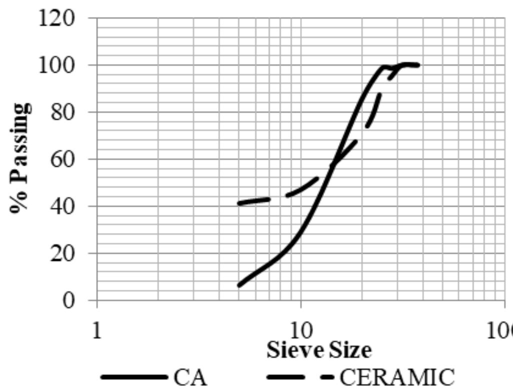

Figure 1. Sieve analysis for ceramic.

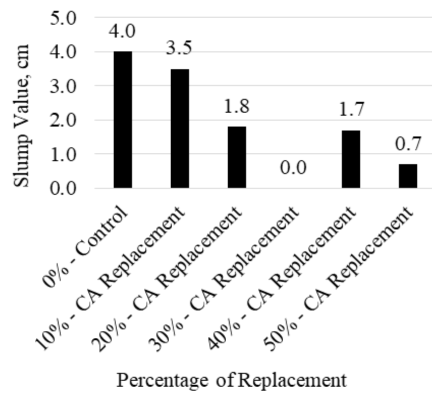

Figure 2. Slump values for different concrete mixes.

3 TESTS RESULTS

3.1 Slump for Plastic State Properties

Slump measured for the six concrete mixtures with different percentages of crushed ceramic wastes replacing the natural coarse aggregate. The values indicate that the slump value decreases by increasing the percentage of ceramic aggregate replacement in the concrete mixture, as shown in Figure 2.

This reduction in slump values while increasing the ceramic aggregate replacement illustrates a high percentage of absorption that might be existing in ceramic aggregates.

3.2 Hardened State Properties

The hardened properties considered herein this study were concrete density, compressive, split tensile, and flexural strengths, which determined according to the adopted code ECP 203 (2018) and BS 1881 (1990) for evaluating and testing the concrete mixtures.

3.2.1 *Concrete strengths at seven days age*

Three strengths were determined: compressive, splitting tensile, and flexural strength through testing the three cube, cylinder, and prism specimens. The results of tested specimens were reported and plotted as in Figure 3. The results showed that the higher the percentage of coarse aggregate replacement by ceramic, the lower the strengths, compressive, splitting, and tensile strength of concrete.

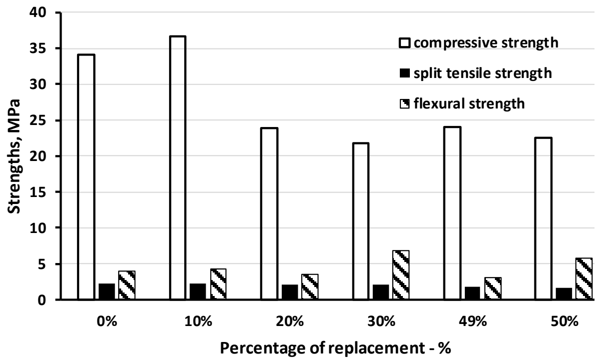

Figure 3. Compressive, split tensile, and flexural strengths of different concrete mixes after 7-days curing.

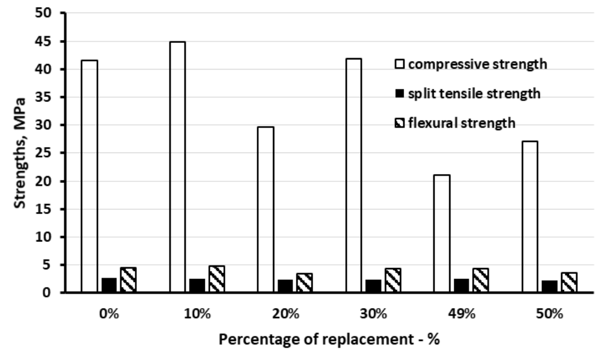

Figure 4. Compressive Strength, split tensile strength, and flexural strength for different concrete mixes after 28-days curing.

3.2.2 *Concrete strengths at 28 days age*

As shown in Figure 4, the results included for the various concrete specimens tested in compression, split tensile and flexural loading for different mixes with replacement percentages 0%, 10%, 20%, 30%, 40%, and 50% of the natural aggregate with ceramic after 28 days. A similar trend observed at seven days was also observed at 28 days. The increase in aggregate replacement by ceramic reduced the compressive, splitting tensile and flexural strengths of concrete. These results indicated that the ceramic aggregate might be weaker in mechanical properties than that of natural aggregate; in addition to, the effect of grains size distribution and physical shape of the ceramic might cause the reduction in strengths as the voids increases due to the high flakiness and elongation of the ceramic aggregate crushed particles. Figures 3 and 4 showed that at 10% percent of ceramic replacement by the coarse natural aggregate, it enhanced the compressive strength by 7.5% at both 7 and 28 days of age. A similar enhancement was obtained for splitting tensile strength by 1.8% and 0.9% at 7 and 28 days of age, respectively. On the other hand, the enhancement in flexural strength was higher than that of control mixtures by 5.5% at both 7 and 28 days of age.

3.3 Density

Figures 5 and 6 show the dry and wet densities assessed to study the effect of replacing the natural coarse aggregate with crushed ceramic aggregate on the own weight when using on any structural element. The results plotted in Figure 5 show that the dry density became lighter when the coarse aggregate replacement percentage by ceramic increases. From Figure 6, the results obtained show a higher density for dry concrete specimens rather than that of wet concrete specimens. However, a similar trend to that of dry density concrete was observed. The increase in ceramic aggregate replacement possesses lighter weight than using the natural aggregate. The ceramic replacement by 30% natural aggregate showed different trends than other mixes in both dry and wet density calculations, which confirm the influence of grain size and shape the physical properties of the concrete produced. It should be mention that the volume of the cube specimen valued 0.003375 cm^3.

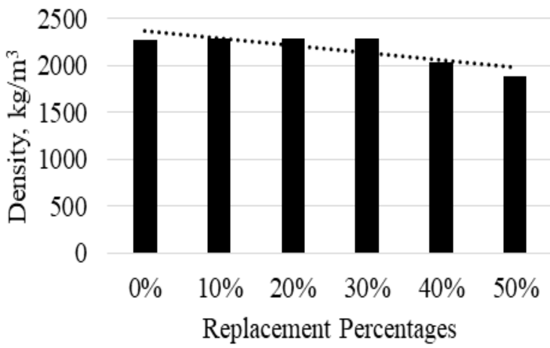

Figure 5. Average dry density of concrete in kg/m^3.

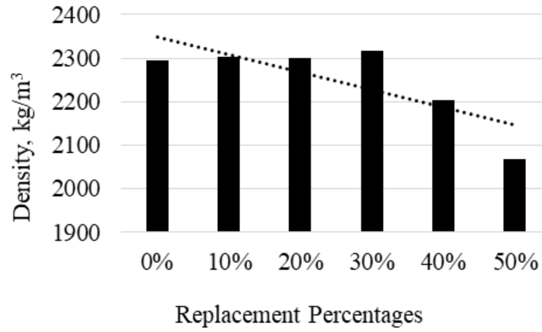

Figure 6. Average wet density of concrete in kg/m^3.

4 CONCRETE MICROSTRUCTURE

4.1 Bond between Cement Paste, Coarse Aggregate, and Ceramic

Figure 7 shows the bond established between the ceramic particles, cement paste, and the natural coarse aggregate. Figure 8 clearly shows that an upper part corresponds to the ceramic particles, and a lower part represents the cement paste particles. From Figure 8, it is clear that the bond ensures the percentage of voids inside the ceramic that is filled by a cement paste, which interferes with the ceramic particles causing strong interlocking between the cement paste and ceramic aggregate.

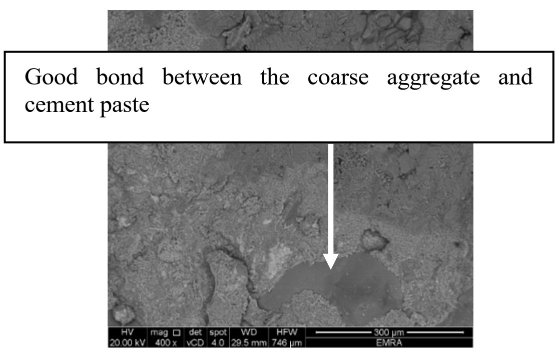

Figure 7. SEM showing the bond between coarse aggregate and cement Paste at the optimum mixture (30% coarse aggregate replacement).

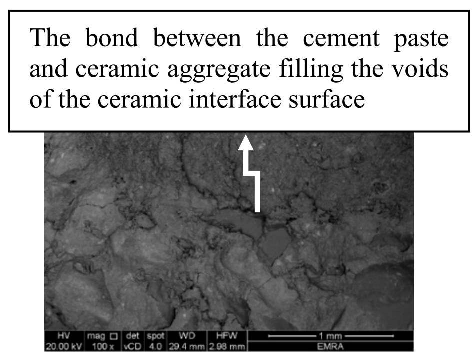

Figure 8. SEM showing the bond between ceramic aggregate and cement Paste at the optimum mixture (30% coarse aggregate replacement).

5 COST ANALYSIS

The cost analysis assessed in Table 3. According to the Egyptian market, the prices calculated by determining the materials cost for the one-meter cube to each material used. The prices updated corresponding to the rates list in April (2018). The percentage of saving in cost by using ceramic waste concrete is around 29 %. Thus, the advantage of using ceramic waste in concrete production economically and environmentally maintained. The application of the concrete produced can apply to non-structural elements till ensuring the durability of this type of concrete, such as pedestrian sidewalks and landscaping or lightweight no-structural elements

Table 3. Cost analysis for ceramic waste concrete.

Material	Weight in Kg	Cost of Material needed for 1 m^3 of Concrete (LE)	Cost of Material needed for 1 m^3 of Ceramic Waste Concrete (LE)	% of saving in cost (LE)
CA	1012.0	79.4	55.6	29
FA	767.2	64.3	51.4	
CEMENT	1474.0	477.0	333.9	
Total		620.7	440.9	

6 CONCLUSION

The ceramic waste worldwide presents about 30 % of the total waste, which is a considerable value to deal with them. Many researchers suggested using the ceramic as recycled aggregate as many other wastes. This study investigated the replacement of ceramic wastes with natural aggregate. The study encountered several mixtures with natural aggregate replacement from 10 to 50%, with an incremental increase of 10%. Several physical and mechanical properties tests were handled over the materials used as concrete constituents. Furthermore, the experimental program is set to assess the mechanical and physical properties of the produced concrete. The performed tests included the concrete specimens of cubes, prisms, and cylinders at 7 and 28 days of age. The results proved the soundness of using the ceramic waste as a replacement for coarse aggregate and revealed that the optimum replacement is around 10%. Moreover, cost analysis studies handled to ensure that this replacement is cost-effective, which reached 29% according to the Egyptian market. The further recommendation noted to investigate the durability of the produced concrete for practical use in terms of structural and non-structural concrete elements

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