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Mechanical Properties of Concrete Incorporating Ceramic Waste Aggregates

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ملخص البحث:
فى هذا البحث تم دراسة امكانية استخدام مخلفات صناعة بلاط السيراميك فى مصر كركام فى الخرسانة. وقد تم تعيين الخواص الطبيعية والميكانيكية لركام السيراميك ومقارنته بالركام التقليدى. وقد تم دراسة تاثير استخدام ركام السيراميك المعاد تدويره كبديل جزئى للركام الكبير أو الصغير فى الخلطات الخرسانية على خواص الخرسانة. وقد تم تحضير ثمانية خلطات خرسانية باستخدام نفس نسبة الماء الى الأسمنت. الأولى خلطة التحكم باستخدام الركام التقليدى (رمل طبيعى وكسر حجارة) وخمس خلطات تم احلال جزء من الركام الكبير بكسر السيراميك بنسب ١٠%، ٢٠%، ٣٠%، ٤٠%، ٥٠%، وخلطتان تم احلال جزء من الركام الكبير والرمل معا بكسر السيراميك بنسبة ٥٠% للركام الكبير، و نسبة ٢٠% للخلطة الأولى و ٤٠% للخلطة الثانية للركام الصغير. وقد تم اجراء اختبار الهبوط لدراسة ثأثير الركام السيراميك على قابلية التشغيل للخرسانة الطازجة. وقد تم اجراء اختبارات الضغط والشد بالانفلاق والانحناء لدراسة الخواص الميكانيكية المستخدم فيها ركام السيراميك. وفد أظهرت نتائج الدراسة المعملية أن استخدام مخلفات صناعة بلاط السيراميك المعاد تدويره كركام للخرسانة يمكن أن يكون واعداً فى صناعة الخرسانة الانشائية.

Abstract:

This paper presents the results of an experimental study to investigate the potential of using recycled ceramic as aggregate in concrete. The ceramic aggregate used in this study was recycled from industrial ceramic tile waste in Egypt. The physical and mechanical characteristics of the recycled ceramic aggregate were investigated and compared to the conventional aggregates. Eight concrete mixes with constant w/c ratio were prepared and tested. The reference concrete mix was made with conventional coarse and fine aggregates (crushed stone and natural sand). Five mixes incorporated coarse ceramic aggregate as a partial substitute of coarse aggregate with replacement levels of 10%, 20%, 30%, 40%, and 50%. Another two mixes incorporated coarse and fine crushed ceramic with replacement levels of 50% for coarse aggregate, and 20% and 40% for fine aggregates. Slump test of the different concrete mixes was conducted to investigate the effect of incorporating ceramic aggregates on the workability of fresh concrete. Compression test, splitting tensile test, and flexural test were accomplished to investigate the mechanical properties of hardened concrete. The experimental results revealed that the use of recycled ceramic tile waste aggregates showed to be promising for the use in structural concrete.

Keywords: *Recycled ceramic, Fine ceramic aggregate, Coarse ceramic aggregate.*

1. Introduction

The use of recycled materials in concrete manufacture has become more widespread in recent years. The use of recycled ceramic tile waste as aggregate in concrete would contribute to relieve industrial waste disposal problems and would help maintain natural aggregate resources [1]. The consumption of recycled ceramic aggregate could reach from 26.9% to 47.6% of the total weight of the fine and coarse aggregates in manufacturing concrete [2].

Fengli et al [2] reported that it is feasible to reuse recycled ceramic aggregate under 9.5 mm as partial replacement of natural aggregate in concrete. Since the apparent density of ordinary concrete is higher than that of recycled ceramic concrete (RCC), this can be helpful to reduce the self- weight of constructions. Under similar workability condition, when the replacement rate is lower than 20%, the splitting tensile strength of RCC is poor because the ultra-fine sand has high mud content. And when the replacement rate is greater than 40%, the compressive strength and splitting tensile strength are higher than those of the reference concrete. The use of 100% recycled ceramic as fine aggregate increases both splitting tensile strength and compressive strength, with ratios 19.85% and 32.73%, respectively.

Torgal et al [3] studied the chemical and physical characteristics of crushed ceramic wastes from landfills. Besides, ceramic powder was used in concrete mixes as partial substitution of cement, while ceramic aggregates were used as a 100% substitution of fine aggregates and 100% substitution of coarse aggregates. They found that compressive strength as well as vacuum water absorption was increases by incorporating ceramic waste in concrete. In another study, Al Bakri et al [4] used different types of recycled ceramic wastes as partial replacement of coarse aggregate in concrete mixes with different w/c ratio; 0.4, 0.5, and 0.7. It was found that all concrete mixes incorporating ceramic aggregates have compressive strength higher than that of conventional concrete.

Halickaet al [5] used ceramic sanitary ware waste as coarse aggregate in concrete mixes. The scanning electron microscopy of the ceramic particles revealed the porosity of their structure. Also, by investigating its properties, it was noticed that ceramic aggregates has low crushing ratio, and high water absorption. They reported that high performance concrete, as well as high abrasion resistance concrete can be obtained by using ceramic sanitary ware waste aggregate with concrete properties not significantly different than that of conventional concrete. In another study, Medina et al [1] used ceramic sanitary ware wastes as partial replacement of gravel. Three mixes were prepared; one as reference concrete and the others with replacement levels 20%, and 25%. The incorporation of ceramic aggregate with natural gravel aggregates slightly raised the porosity. Both compressive strength and tensile splitting strength increased as replacement percentage increases. In addition, concrete mixes with recycled ceramic aggregate has lower slump, lower density, higher water absorption, higher sorpitivity, and higher porosity compared to that of reference concrete.

On the other hand, De Brito et al [6] incorporated ceramic wastes, from construction and demolition wastes, in concrete mixes as a partial replacement of coarse aggregate. They prepared four concrete mixes with replacement ratios of0, 1/3, 2/3, and 3/3. It was found that as replacement percentages increases, compressive strength, Flexural strength, and loss of thickness by abrasion decreased compared to conventional concrete. They reported that since ceramic aggregates have high water absorption, this can be overcome by restoring to pre-saturation procedure. Corominas and Etxeberria [7] prepared concrete mixes incorporating mixed recycled aggregate from construction and demolition treatment plant as partial substitution of coarse aggregate with replacement levels 20%, 50%, and 100%, in addition to preparing mixes incorporating fine ceramic aggregate as a partial replacement of sand with levels 15%, and 30%. They reported that the use of 30% fine ceramic aggregate decreases density of concrete. The mechanical properties such as compressive strength, splitting tensile strength, and flexural strength are slightly differing than that of conventional concrete. Sorptivity, water absorption, and voids increased more than reference concrete. It was concluded that concrete made up to 20% recycled mixed aggregates achieved similar compressive strength as conventional concrete.

2. Experimental Work

The experimental work aimed to investigate the potential of using ceramic tile waste as aggregate in concrete. The experimental program was designed to achieve the following:

1. Determine the physical and mechanical characterization of recycled ceramic tile waste aggregate.
2. Studying the effect of using recycled ceramic tile waste as partial replacement of fine and coarse aggregates, on the properties of fresh and hardened concrete.

2.1Materials

The concrete mix constituent materials were: ordinary Portland cement (CEM I 42.5R) provided by the Arabian Cement Company which compiles with EN 197-1[8], natural siliceous sand with fineness modulus 2.68, and crushed stone with particle size of 5-20 mm and nominal maximum size 20 mm. A high range water reducing and set retarding concrete admixture "Sikament R 2004" complying with ASTM C 494 Type G was used as a superplasticizer with a constant content (1.5% by weight of cement).

Recycled ceramic aggregates

Ceramic tile wastes were crushed into small pieces using a crusher, and then sieved to get the required coarse ceramic aggregate particles with sizes ranging from 5 to 20 mm. The fine ceramic aggregate was obtained by sieving the fine crushed ceramic to get particles with sizesranging from 2.36 mm to 150 µm. The coarse and fine recycled ceramic aggregates used in this study are shown in Figure (1). The characteristics of both conventional and ceramic aggregates were determined according to EN 933[9].

Coarse ceramic aggregate   Fine ceramic aggregate

Figure (1): Recycled ceramic tile waste aggregates

3.1Mix proportions

The reference concrete mix was designed to meet 25 MPa using conventional coarse and fine aggregates with water to cement ratio W/C= 0.55. Ten concrete mixes incorporating recycled ceramic aggregates were used in this study with the same W/C. Five mixes incorporated coarse ceramic aggregate as a partial substitute of crushed stone with replacement levels of 10%, 20%, 30%, 40%, and 50%. The other two mixes; C50 F20 was made of 50% replacement of crushed stone with coarse ceramic aggregates, and 20% replacement of natural sand with fine ceramic aggregate, while C50 F40 was made of 50% replacement of crushed stone with coarse ceramic aggregates, and 40% replacement of natural sand with fine ceramic aggregate. Concrete mixes were identified according to the ceramic aggregate replacement level as a partial substitute of coarse or fine aggregate. The mix proportions of the different concrete mixes are given in Table (1).

Table (1): Mix proportions (Kg/m^3)

Mix ID	Cement	Coarse aggregate	Coarse ceramic aggregate	Sand	Fine ceramic aggregate	Water	Super-plasticizer
CL	387	1075	0	713	0	212	5.8
CCA10	387	960	107	713	0	212	5.8
CCA20	387	840	210	713	0	212	5.8
CCA30	387	724	310	713	0	212	5.8
CCA40	387	611	407	713	0	212	5.8
CCA50	387	502	502	713	0	212	5.8
C50F20	387	512	512	546	137	212	5.8
C50F40	387	539	539	407	271	212	5.8

3.2Tests and specimens preparation

Slump of all concrete mixes were determined according to EN 12350-2 [10]. Cubic specimens of dimensions 100 x 100 x 100 mm were prepared to be tested at 7 days, and 28 days and compressive strength of concrete was determined according to EN 12390-3 [11]. In addition, density of hardened concrete was conducted according to EN 12390-7

[12]. While indirect tension test was conducted according to EN 12390-6 [13] using cylinders with dimensions 100 mm in diameter and 200 mm in height. Moreover, flexural strength was determined according to EN 12390-5 [14] using 100 x 100 x 500 mm prisms.

4. Test Results and Discussion

4.1 Properties of aggregates

The particle size distribution of the used ceramic and conventional coarse and fine aggregates is summarized in Tables (2) and (3). It was seen that the ceramic coarse and fine aggregates satisfied the specification limits for aggregates. The nominal maximum size for both, ceramic coarse aggregate and crushed stone is 20 mm.

Table (2): Particle size distribution of coarse aggregates

Sieve size (mm)		4.75	10	20	37.5
Passing (%)	Natural coarse aggregate (5-20mm)	2.37	59.68	100	100
	Ceramic coarse aggregate (5-20mm)	5.84	39.65	100	100
	Specification limits (5-20mm)	0-10	30-60	90-100	100

Table (3): Particle size distribution of fine aggregates

Sieve size (mm)		4.75	2.36	1.18	0.600	0.300	0.150
Passing (%)	Natural sand	100	97.50	92.80	54.17	9.53	3.01
	Ceramic fine aggregate	100	97.19	69.13	33.5	17.23	9.30
	Specification limits (Medium)	100	65-100	45-100	25-80	5-48	-

The results show that the ceramics waste coarse aggregate satisfied the aggregate specification limits. The specific gravity for ceramic waste is 2.38 whereas for crushed stone is 2.63. The maximum size for both, ceramic waste and crushed stone are the same, i.e. 20 mm. The water absorption for ceramic waste is 5.5% whereas for crushed stone is 1.8%. In general, ceramic waste aggregate showed properties closed to those of natural crushed stone aggregate. The mechanical and physical properties of natural and ceramic aggregates are revealed in Table (4).

Table (4): Mechanical and physical properties of coarse aggregates

Property	**Aggregate**		**Ceramic**		**Specification limits**
	Coarse	**Sand**	**Coarse**	**Fine**	
Bulk specific gravity	2.557	-	2.066	-	
Apparent specific gravity	2.680	2.667	2.331	2.494	
Water absorption (%)	1.8%	-	5.5%	-	3%
Bulk density (Kg/m3)	1494.4	1630	1330.4	1204	
Voids (%)	41.43	-	35.48	-	
Loss in weight (%) “Loss Angeles”	22.20	-	27.10	-	30%

Elongation Index (%)	2.04	-	10.39	-	15%
Flakiness Index (%)	1.36	-	14.11	-	15%
Clay lumps and friable particles (%)	-	2.2	-	6.0	3%
Fineness Modulus	-	2.44	-	2.74	

The properties of ceramic coarse and fine aggregates were found to comply with specification limits except for water absorption of ceramic coarse aggregate and clay lumps of ceramic fine aggregates which were higher than that specified by specification limits.

The scanning electron microscopy of the used fine ceramic aggregate revealed that its surface texture has irregular shape, rough surface, and sharp edges. The fine glazed particles were presented as white particles as shown in Figure (2).

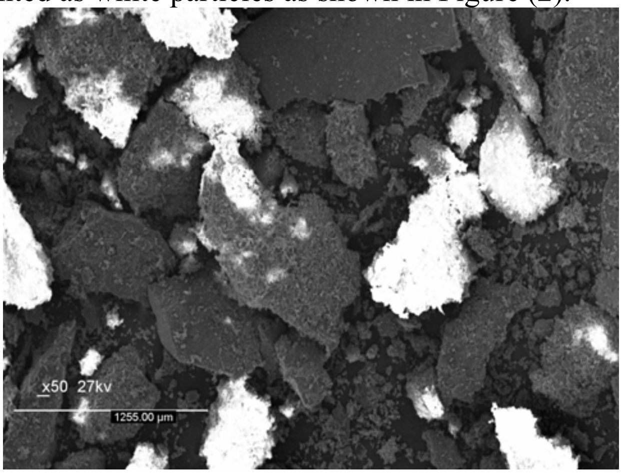

Figure (2): SEM of fine ceramic aggregate

4.2 Properties of concrete incorporating ceramic waste aggregates

4.2.1 Slump of concrete mixes

It was found that as replacement percentage of aggregates increases, slump decreases as shown in Figure (3). When replacement level reached 50%, the loss in slump was 61.1%, while loss in slump reached 91.6% for mix C50F40. This is due to the high water absorption of ceramic aggregate.

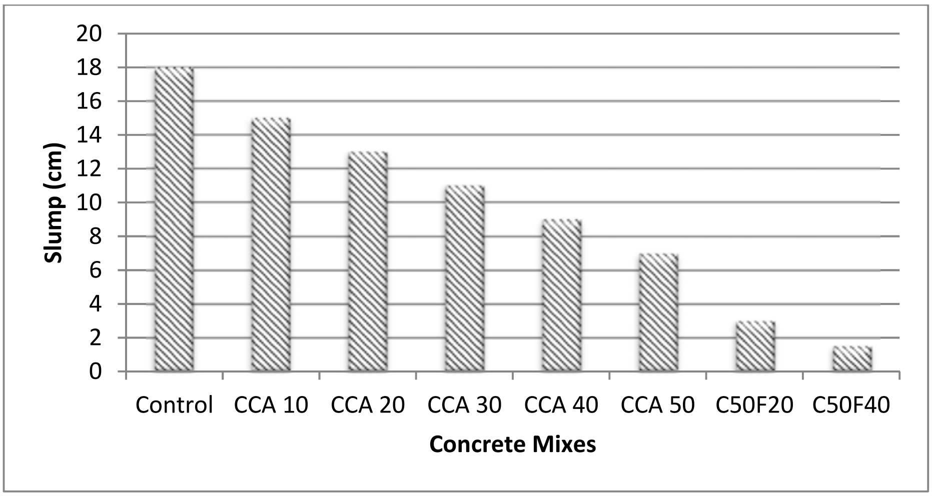

Figure (3): Slump of concrete incorporating recycled ceramic aggregates

4.2.2 Compressive strength

The compressive strength results are shown in Figure (4). These results illustrates that by using coarse ceramic aggregate with replacement levels of 10%, 20%, 30%, 40%, and 50%, the compressive strength at 7-days increased by 7.20%, 10.04%, 12.53%,14.30%, and 18.92%, respectively, while the compressive strength at 28-days increased by 9.18%, 11.35%, 12.89%, 16.51%, and 24.74%, respectively compared to that of the reference concrete. While by using mixed ceramic aggregates, the compressive strength of mixes C50F20 and C50F40 increased by 66.24% and 56.20% respectively at 7-days and by 47.92% and 36.09% respectively at 28-days compared to that of the reference concrete.
It was noticed that compressive strength increases as replacement level with coarse ceramic aggregate increases. This may be due to the decrease of free-water in concrete mix since ceramic aggregate has high water absorption.

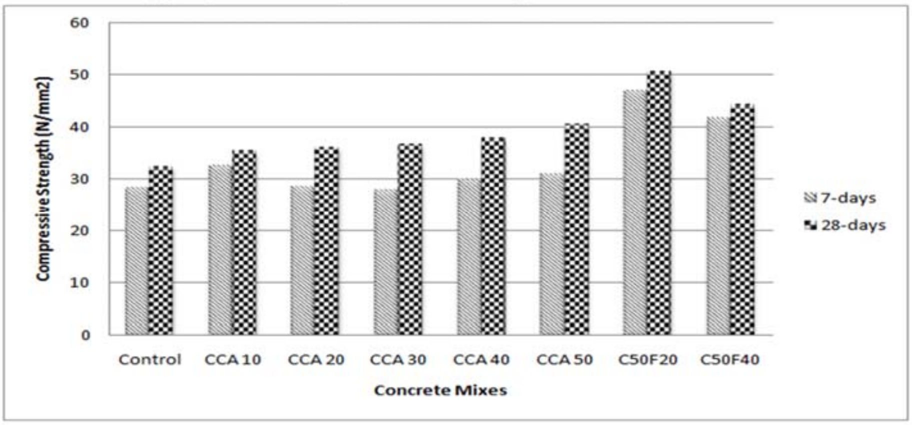

Figure (4): Compressive strength of concrete incorporating recycled ceramic aggregates

4.2.3 Splitting tensile strength

The splitting tensile test results are shown in Figure (5). On using coarse ceramic aggregate as well as mixed ceramic aggregates as partial replacement of natural aggregates, the splitting tensile strength of concrete mixes with ceramic aggregates slightly differs than that of the control mix.

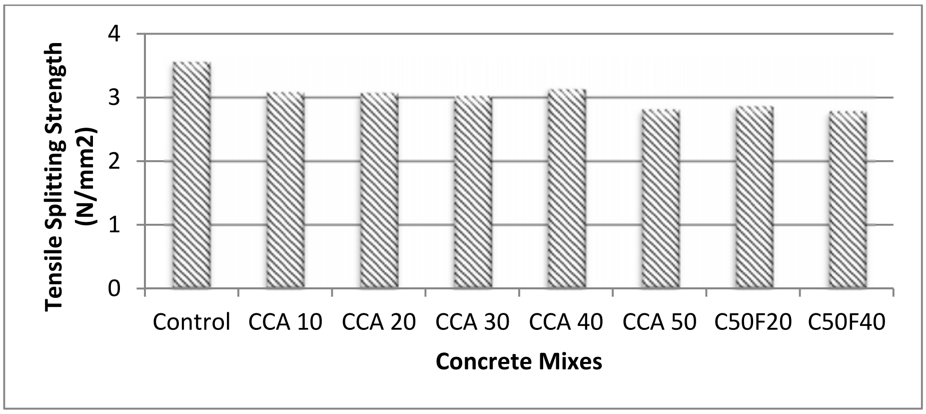

Figure (5): Splitting tensile strength of concrete incorporating recycled ceramic aggregates

4.2.4 Flexural strength

The flexural strength test results are shown in Figure (6). It can be noticed that the flexural strength of concrete mixes incorporating coarse ceramic aggregate slightly decreases with the increase in coarse aggregate replacement level. While the flexural strength of mixes C50F20, and C50F40 increased by 34.95%, and 24.27% respectively compared to reference concrete.

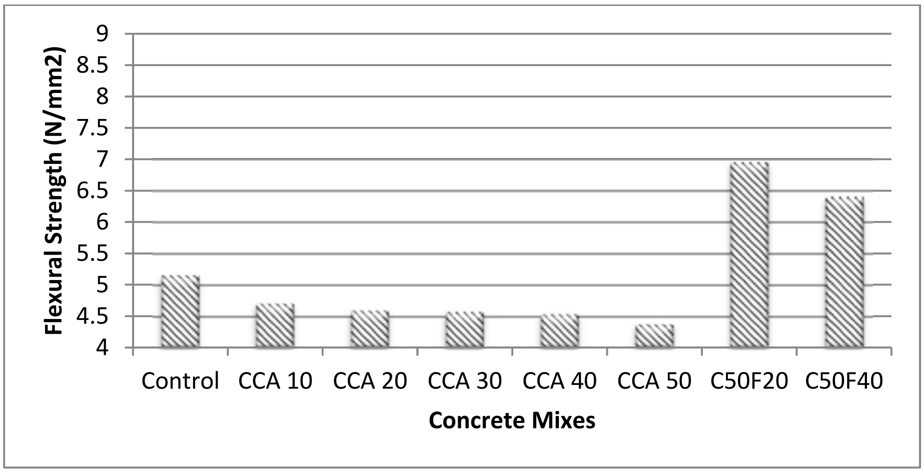

Figure (6): Flexural Strength of concrete incorporating recycled ceramic aggregates

7. Conclusions

Based on the results of the experimental work carried out in this research, it was concluded that:

1. The physical and mechanical characteristics of waste ceramic aggregates are nearly the same as natural aggregates.
2. While slump decreases in general with the increase in waste ceramic aggregates replacement level.
3. Compressive strength increases as replacement level increases. The increase in compressive strength was nearly 25%, and 51% for CCA 50, and C50F20, respectively.
4. No significant difference was detected in tensile strength in case of replacing coarse ceramic aggregates, while the decrease in flexural strength reached 15% in case of 50% replacement ratio.
5. Ceramic aggregates have properties similar to natural aggregates and so it can be used in concrete.

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