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UTILIZATION OF SOLID WASTES IN CEMENT BRICKS FOR AN ENVIRONMENTAL BENEFICIAL

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ABSTRACT: The building materials industry generates secondary products or wastes, which have a direct effect on the environment. The storage of such wastes in dumps pollutes the air and contaminates water sources and agricultural fields. There is a tremendous scope for recycling and using such huge quantity of wastes to minimize their environmental impact. This paper investigates the effect of partial/full replacement of conventional aggregates with recycled aggregates in manufacturing of solid cement bricks. Three series of recycled aggregates were used namely; quarry waste, marble waste and crushed ceramic. In each series, either conventional coarse aggregate, fine aggregate, or coarse and fine aggregates simultaneously were replaced with one of the following wastes: quarry waste, marble waste or crushed ceramic. Each type of wastes replaced conventional aggregate at different percentage (0%, 25%, 50%, 75% or 100%). Compressive strength, flexural strength, and water absorption were determined and compared with the relevant standards. It was found that it is feasible to recycle quarry waste, marble waste and crushed ceramic as aggregate in the production of solid cement bricks from the technical, economical and environmental point of view as they will conserve natural resources, protect the environment from waste disposal, and produce a low cost product and higher quality product than the conventional one.
KEYWORDS: Solid cement bricks; Waste; Compressive strength; Water absorption

INTRODUCTION

Huge quantities of solid wastes are being generated from different industrial, mining, agricultural and domestic activities causing major environmental problems from their disposal and occupying a large area of lands for their storage/disposal. Thus, there is a tremendous scope for recycling these wastes in environmentally and economically sustainable ways as minerals or resources in the production of construction materials. These wastes can either be used as part of the cement mixture or as aggregate in concrete in order to protect the environment from their disposal and to conserve natural resources.

Quarry waste is a by-product generated during the extraction and crushing process of rocks to produce aggregates. It is generally in the form of fine particles less than 4.75mm [1-3]. Recent investigations in UK indicate that 106 million tonnes of limestone rock, usually crushed at quarry sites, has been extracted during 2002, and produced nearly 22 million tonnes of fines in industrial sections. Further to UK and as examples, production of annually 18 million tones of limestone dust in Greece and 30 million tones in Turkey have been reported. Quarry waste typically does not have a significant demand due to the high content of fines, with diameters less than 80 μm, that exceeds the standard allowable limit of 5% [3]. Usually, quarry waste is used in large scale in the highways as a surface finishing material and can be also used for manufacturing of hollow blocks and lightweight concrete prefabricated elements. Using quarry waste as a substitute of aggregate in construction materials would resolve the environmental problems caused by the large-scale depletion of the natural sources. It was reported that the use of quarry waste as a fine aggregate in concrete draws serious attention of researchers and investigators [1].

USA, Belgium, France, Spain, Sweden, Italy, Egypt, Portugal, Brazil and Greece are among the countries with considerable marble reserves [4]. One of the major waste generating industries is the marble production industry [5]. In processing marble such as cutting to size and polishing etc. for decorative purposes, marble dust and aggregate are created as by-products [4]. It was reported that a high volume of marble production generates a considerable amount of waste materials; almost 70% of this mineral gets wasted in the mining, processing and polishing stages [4, 6]. Almost 40% of the waste generated during quarrying operations is mainly in the form of rock fragments [5]. Thus, waste *materials from marble processing plants represent millions of tons [4]. Such waste is often dumped near residential areas, into nearby empty pits, on roads, pasturelands and agricultural fields, or onto riverbeds thereby threatening the porosity of aquifer zones leading to wide-spread environmental pollution [4, 5]. Many studies have been conducted in literature on the performance of the concrete containing waste marble dust or waste marble aggregate, such as its addition into self compacting concrete as an admixture or sand, as well as its utilization in asphaltic concrete, as an additive in cement production, as a coarse or fine aggregate in concrete.*

Crushed ceramic resulted from the crushing of earthenware in ceramic industries (such as the producing vases, teapots, small earthen pots, or other porcelains) which may cracked during the sintering process and account about 30% of the overall production of the ceramic industry. It may be also resulted from demolition wastes as it accounts about 30% of all demolition wastes. Although the ceramic industries have attempted to find appropriate solutions for waste disposal, ceramic waste cannot presently be reused in the production of new material [7, 8]. Although crushed ceramic has several positive features: it is hard, durable, and highly resistant to chemicals, it is not being recycled at present and it is dumped to landfill [8]. Crushed ceramic can be used as road fill, as a partial substitute for natural aggregate in concrete, either as coarse aggregate or as fine aggregate, and as a substitute – in varying proportions – for cement in mortar and concrete [8-10].

The aim of this work is to study the effect of recycling some types of solid wastes generated from the quarrying, processing and industrial practices as coarse and fine aggregate in the production of solid cement bricks to reduce the impact that the environment can suffer from the consumption of natural aggregates and the random disposal of wastes.

EXPERIMENTAL PROCEDURE - Materials

The used cement was produced by El-Suez Cement Company designated as CEM I 42.5N. Sand and crushed stone with nominal maximum size of 10 mm were used as fine aggregate (FA) and coarse aggregate (CA), respectively. Three types of wastes; quarry waste, marble waste and crushed ceramic were used as recycled coarse and fine aggregates. Coarse quarry waste was that passed from sieve 4.76 mm and retained on sieve 2.38 mm, and fine quarry waste was that passed from sieve 2.38 mm. Coarse marble waste was that passed from sieve 14 mm and retained on sieve 4.76 mm, and fine marble waste was that passed from sieve 4.76 mm. Coarse crushed ceramic was that passed from sieve 14 mm and retained on sieve 4.76 mm, and fine crushed ceramic was that passed from sieve 4.76 mm. The aggregates properties are shown in Table 1.

Methods - Mixture proportions

Three series of mixtures with constant cement content 200 kg/m3 were prepared. In each series, either natural fine aggregate, coarse aggregate or both were replaced with quarry waste, marble waste, or crushed ceramic. For each series, ten different mixtures were manufactured to examine the influence of using these wastes as coarse and fine aggregate in solid cement bricks.

The first series (series I) includes quarry waste which was used to replace either coarse aggregate at 0%, 25%, 50%, 75% and 100%, fine aggregate at 0%, 25%, 50%, 75% and 100%, or replacing 75% coarse aggregate and 25% fine aggregate simultaneously.

The second series (series II) includes marble waste which was used to replace either coarse aggregate at 0%, 25%, 50%, 75% and 100%, fine aggregate at 0%, 25%, 50%, 75% and 100%, or replacing 75% coarse aggregate and 25% fine aggregate simultaneously. Finally, the third series (series III) includes crushed ceramic which was used to replace either coarse aggregate at 0%, 25%, 50%, 75% and 100%, fine aggregate at 0%, 25%, 50%, 75% and 100%, or replacing 25% coarse aggregate and 75% fine aggregate simultaneously. All mixtures were designed to have an almost zero slump to be compared on a common basis. Mixtures proportions are shown in Tables 2 to 4.

Table 1. Physical properties of aggregates [1]

Property	Coarse aggregate				Fine aggregate				Limits
	CS	QW	MW	CC	CS	QW	MW	CC	
Specific gravity (SSD)	2.70	2.86	2.72	2.20	2.5	2.63	2.50	2.17	-
Unit weight (t/m^3)	1.67	1.46	1.51	1.24	1.62	1.80	1.51	1.44	-
Absorption (%)	1.53	1.60	0.30	3.40	-	-	-	-	≤2.5[3]
Fineness modulus	0.12	0.06	-	-		-			—
Clay and fine materials (%)	-	-	0.73	0	1.40	11.00	6.00	9.70	≤ 4%[2]
Impact index (%)	14.60	-	25.00	13.40	-	-	-	-	≤ 45[2]
Flakiness index (%)	14.30	-	14.70	16.60	-	-	-	-	≤ 25[3]
Elongation index (%)	16.60	-	18.20	17.30	-	-	-	-	≤ 25[3]
Abrasion resistance (%)	18.40	-	-	26.40	-	-	-	-	≤ 30[2]

(1) CS: Crushed stone, QW: Quarry waste, MW: Marble waste, CC: Crushed ceramic
(2) According to the Egyptian Standard Specifications No. 1109/2002 [12]
(3) According to Egyptian code of practice issued 2007 [13]

Table 2. Mixtures proportions of series I (quarry wastes series)

Mix	Identification of mix	Cement	Water	Coarse aggregate		Fine aggregate	
				CS	QW	Sand	QW
1	Control	200	156	1188	——	792	——
2	25% CA	200	159	891	297	792	——
3	50% CA	200	159	594	594	792	——
4	75 % CA	200	159	297	891	792	——
5	100% CA	200	154	——	1188	792	——
6	25% FA	200	159	1197	——	598	199.5
7	50% FA	200	140	1206	——	402	402
8	75% FA	200	130	1216	——	203	608
9	100% FA	200	118	1226	——	——	817
10	75% CA+ 25% FA	200	163	299	898	598	199.5

Table 3. Mixtures proportions of series II (marble wastes series)

Mix	Identification of mix	Cement	Water	Coarse aggregate		Fine aggregate	
				CS	MW	Sand	MW
1	Control	200	156	1188	——	792	——
2	25% CA	200	200	891	297	792	——
3	50% CA	200	141	594	594	792	——
4	75 % CA	200	136	297	891	792	——
5	100% CA	200	132	——	1188	792	——
6	25% FA	200	151	1197	——	598	199.5
7	50% FA	200	141	1206	——	402	402
8	75% FA	200	136	1216	——	203	608
9	100% FA	200	132	1226	——	——	817
10	75% CA+ 25% FA	200	131	299	898	598	199.5

Table 4. Mixtures proportions of series III (crushed ceramic series)

Mix	Identification of mix	Cement	Water	Coarse aggregate		Fine aggregate	
				CS	CC	Sand	CC
1	Control	200	156	1188	——	792	——
2	25% CA	200	156	891	297	792	——
3	50% CA	200	190	594	594	792	——
4	75 % CA	200	201	297	891	792	——
5	100% CA	200	204	zero	1188	792	——
6	25% FA	200	172	1185	——	592	197.5
7	50% FA	200	181	1185	——	395	395
8	75% FA	200	195	1185	——	197.5	592
9	100% FA	200	216	1185	——	——	790
10	25% CA+ 75% FA	200	206	296	——	197.5	593

Mixing, curing, and testing

Solid cement bricks with dimensions 25×12×6 cm were manufactured by using conventional mixer and mechanical press used in bricks factories. The manufactured bricks were demoulded within few seconds after compacting of the mixed constituent materials in a mould, as the bricks are required to be self-supporting from the moment they are extruded. After demoulding, the manufactured bricks were left in ambient conditions for 24 h, and then they were cured by water sprinkling twice per day for 28 days. Figure 1 shows the bricks just after pressing.

Figure 1. Solid cement bricks

The manufactured solid cement bricks were tested after 7, 28, 120 and 180 days of curing according to ES 48,619/2003 [11] to determine the compressive strength, flexural strength and water absorption. Each result is the average of five bricks. The results were checked for compliance with ES 1292/1[14] for load bearing units as well as ES 1292/2 [15] for non-load bearing units, respectively. Furthermore, the results were compared with the properties of the control solid cement bricks manufactured with conventional aggregates.

RESULTS AND DISCUSSION - Compressive Strength

According to the Egyptian Standard Specifications (ESS) 1292-1 and 1292-2 [14,15] , the compressive strength for a solid cement brick should not be less than 131 kg/cm^2 and 41.4 kg/cm^2 if used as load bearing unit, non load bearing units, respectively.

Figure 2 shows the compressive strength for solid cement bricks produced with quarry waste as a function of replacement percentage of aggregate and curing age. Using of coarse quarry waste enhanced the compressive strength of solid cement bricks up to 75% replacement percentage compared with the control bricks produced with conventional aggregates. The increase in compressive strength for 75% replacement percentage of coarse aggregate with coarse quarry waste was 14.9%, 15.4%, 14.4%, and 13.6% at 7, 28, 120, and 180 days, respectively compared with the control bricks. On the other hand, the compressive strength decreased by increasing the replacement percentage of natural fine aggregate by fine quarry waste.

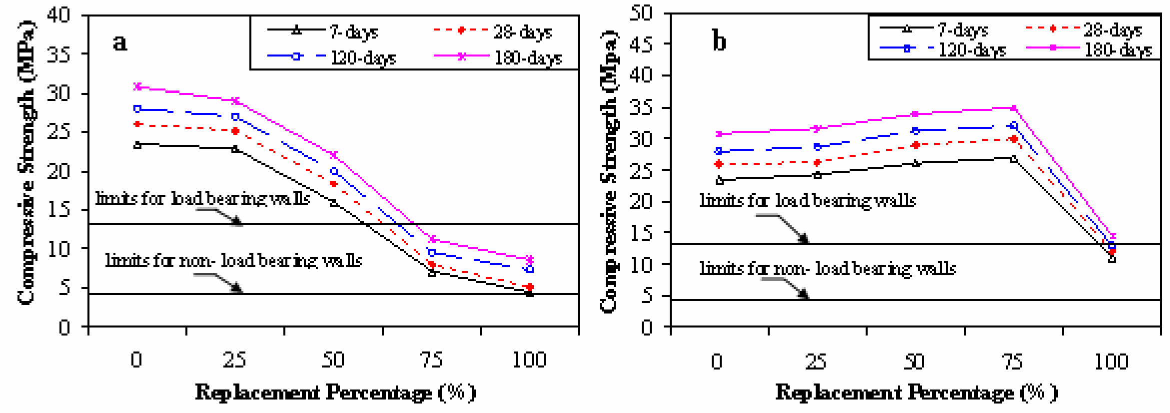

Figure 2. Effect of quarry waste on the compressive strength of bricks
(a) Fine quarry waste, (b) Coarse quarry waste

The decrease in compressive strength for 100% replacement percentage of fine aggregate with fine quarry waste was 81.2%, 80.3%, 73.9%, and 72.1% at 7, 28, 120, and 180 days, respectively compared with the control bricks. It should be noted that replacing of 75% coarse aggregate or 50% fine aggregate by coarse or fine quarry waste, respectively provided a product with compressive strength satisfying the requirements of ESS for load bearing units, while the replacement percentage 100% of coarse aggregate or 75% of fine aggregate by quarry waste provided a product with 28-day compressive strength satisfying the requirements of ESS for non-load bearing units.

Figure 3 shows the compressive strength for solid cement bricks produced with marble waste as a function of replacement percentage of aggregate and curing age. Using of marble waste to replace up to 75% of coarse aggregate or 25% of fine aggregate enhanced the compressive strength of solid cement bricks compared with the control bricks produced with conventional aggregates.

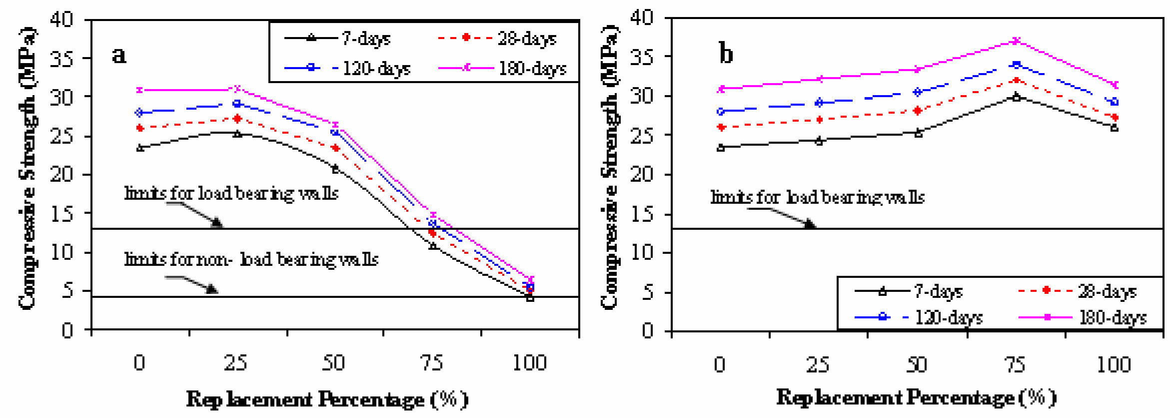

Figure 3. Effect of marble waste on the compressive strength of bricks
(a) Fine marble waste, (b) Coarse marble waste

The increase in compressive strength for 75% replacement percentage of coarse aggregate with coarse marble waste was 27.7%, 23.1%, 21.4%, and 20.1% at 7, 28, 120, and 180 days, respectively compared with the control bricks. On the other hand, the increased in compressive strength for 25% replacement percentage of fine aggregate with fine marble waste was 7.7%, 5%, 4.6%, and 0.6% at 7, 28, 120, and 180 days, respectively compared with the control bricks. It should be noted that replacing of 100% coarse aggregate or 50% fine aggregate by coarse or fine marble waste, respectively provided a product with 28-day compressive strength satisfying the requirements of ESS for load bearing units, while the replacement percentages 75% and 100% of fine aggregate by marble waste provided a product with 28-day compressive strength satisfying the requirements of ESS for non-load bearing units.

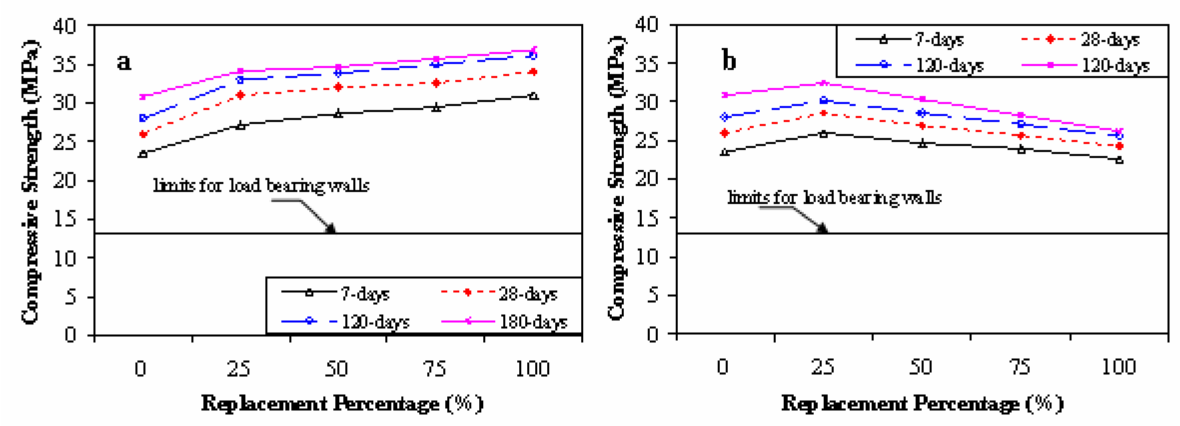

Figure 4. Effect of crushed ceramic on the compressive strength of bricks (a) Fine crushed ceramic, (b) Coarse crushed ceramic

Figure 4 shows the compressive strength for solid cement bricks produced with crushed ceramic as a function of replacement percentage of aggregate and curing age. Using of 25% coarse crushed ceramic or up to 100% fine crushed ceramic enhanced the compressive strength of solid cement bricks compared with the control bricks produced with conventional aggregates. The increase in compressive strength for 25% replacement percentage of coarse aggregate with coarse crushed ceramic was 10.6%, 9.6%, 7.5%, and 5.2% at 7, 28, 120, and 180 days, respectively, while the increase for 100% replacement percentage of fine aggregate with fine crushed ceramic was 31.9%, 30.8%, 29.1%, and 19.6% at 7, 28, 120, and 180 days, respectively compared with the control bricks. It should be noted that replacing of 100% coarse aggregate or 100% fine aggregate by coarse or fine marble waste, respectively provided a product with 28-day compressive strength satisfying the requirements of ESS for load bearing units.

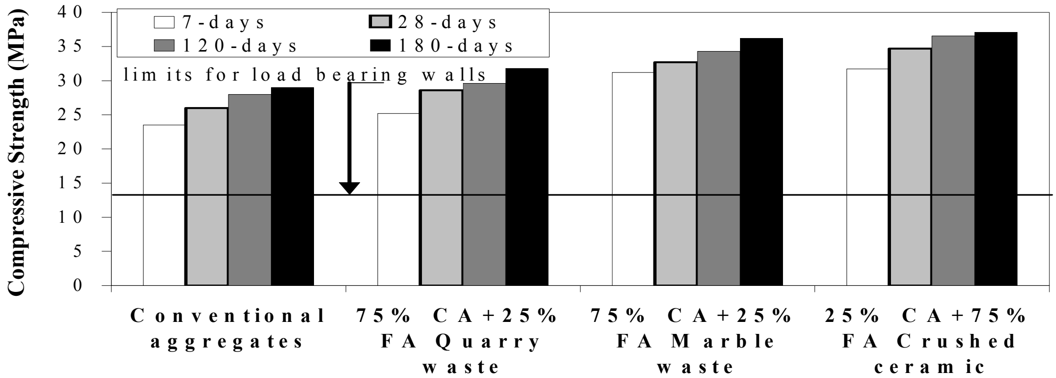

Figure 5. Effect of recycled aggregate type on the compressive strength of solid cement bricks

Figure 5 shows the effect of recycled aggregate type on the compressive of solid cement bricks at ages 7, 28, 120 and 180 days. It should be noted that the mixes presented in this figure includes the control mix and mixes including recycled aggregates (quarry waste, marble waste and crushed ceramic) replacing coarse and fine aggregates simultaneously. The percentages of fine and coarse recycled aggregates in these mixes are 75% and 25%, respectively for either quarry waste or marble waste, and 25% and 75%, respectively for crushed ceramic. The compressive strength values for solid cement bricks containing recycled aggregates (quarry waste, marble waste, or crushed ceramic) as coarse and fine aggregates were higher than those for the control bricks produced with conventional aggregates. The use of quarry waste, marble waste and crushed ceramic as fine and coarse aggregates simultaneously increased the 28-day compressive strength of bricks by 10%, 25.8% and 33.5%, respectively compared with the control bricks. By comparing the strength of solid cement bricks containing fine and coarse recycled aggregates it can be found that crushed ceramic bricks had the highest strength while quarry waste showed the lowest strength. Moreover, the replacement of 25% of fine aggregate and 75% of coarse aggregate simultaneously by quarry waste or marble waste, or the replacement of 75% of fine aggregate and 25% of coarse aggregate simultaneously by crushed ceramic provided a product with 28-day compressive strength satisfying the requirements of ESS for load bearing units.

Flexural Strength

The flexural strength of the produced solid cement bricks was determined after 28 days from casting. It should be noted that there is no limits for the flexural strength for solid cement bricks in the Egyptian Standard Specifications.

Figure 6 shows the effect of using quarry waste as coarse or fine aggregate on the flexural strength of bricks. Using of coarse quarry waste enhanced the flexural strength of solid cement bricks up to 75% replacement percentage compared with the control bricks produced with conventional aggregates. The increase in flexural strength for 75% replacement percentage of coarse aggregate with coarse quarry waste was 12.7% compared with the control bricks. On the other hand, the flexural strength decreased by increasing the replacement percentage of natural fine aggregate by fine quarry waste.

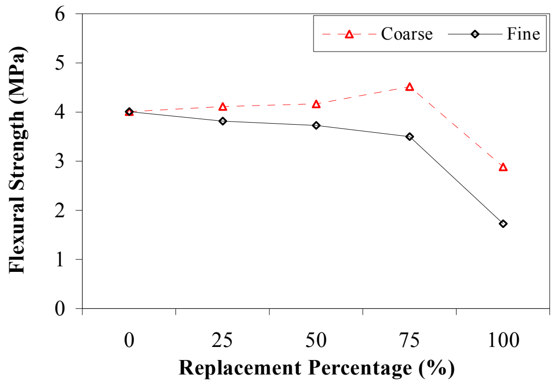

Figure 6. Effect of quarry waste on the flexural strength of bricks

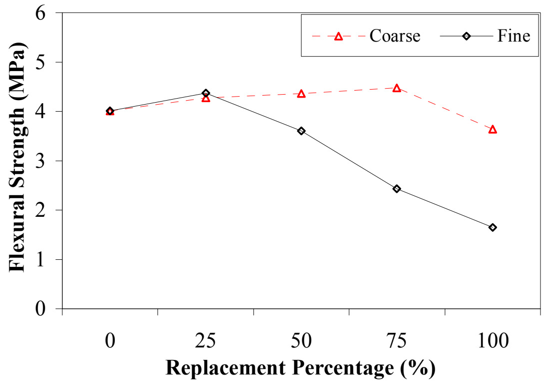

Figure 7. Effect of marble waste on the flexural strength of bricks

Figure 7 shows the effect of using marble waste as coarse or fine aggregate on the flexural strength of bricks. The flexural strength increased by using either coarse or fine marble waste up to 75% and 25%, respectively to replace natural aggregates. The increase in flexural strength for 75% replacement percentage of coarse aggregate with coarse marble waste was 11.7% compared with the control bricks, while the increase in flexural strength for 25% replacement percentage of fine aggregate with fine marble waste was 9% compared with the control bricks.

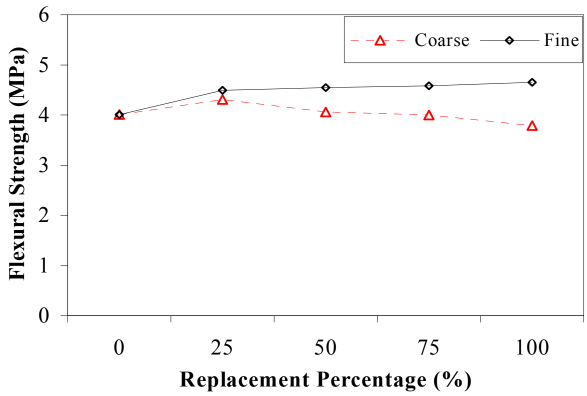

Figure 8. Effect of crushed ceramic on the flexural strength of bricks

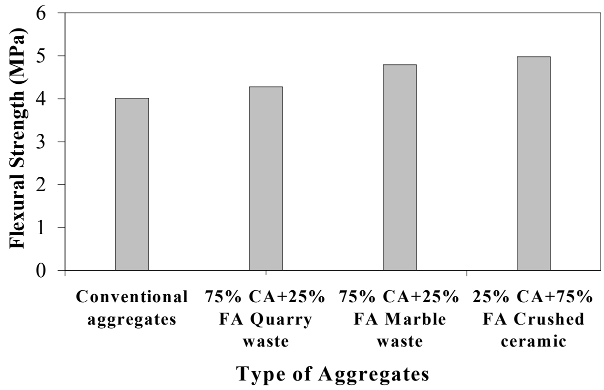

Figure 9. Effect of recycled aggregate type on the flexural strength of bricks

Figure 8 shows the effect of using crushed ceramic as coarse or fine aggregate on the flexural strength of bricks. The flexural strength increased by increasing the replacement percentage of natural coarse aggregate by coarse crushed ceramic up to 25% replacement percentage, then it showed a slight loss with increasing the replacement percentage. The increase in flexural strength for 25% replacement percentage of coarse aggregate with coarse crushed ceramic was 7.5%. On the other hand, the flexural strength increased by increasing the replacement percentage of natural fine aggregate by fine crushed ceramic. The increase in flexural strength for 100% replacement percentage of fine aggregate with fine crushed ceramic was 16.0%.

Figure 9 shows the effect of recycled aggregate type on the flexural of solid cement bricks. As stated previously that the mixes presented in this figure includes the control mix and mixes including recycled aggregates (quarry waste, marble waste and crushed ceramic) replacing coarse and fine aggregates simultaneously. The percentages of fine and coarse recycled aggregates in these mixes are 75% and 25%, respectively for either quarry waste or marble waste, and 25% and 75%, respectively for crushed ceramic. The flexural strength values for solid cement bricks containing recycled aggregates (quarry waste, marble waste, or crushed ceramic) as coarse and fine aggregates were higher than those for the control bricks produced with conventional aggregates. The use of quarry waste, marble waste and crushed ceramic as fine and coarse aggregates simultaneously increased the flexural strength of bricks by 6.7%, 19.5% and 24.1%, respectively compared with the control bricks. By comparing the strength of solid cement bricks containing fine and coarse recycled aggregates it can be *found that crushed ceramic bricks showed the highest strength while quarry waste showed the lowest strength.*

Water Absorption

Figure 10 shows the effect of replacement percentage of coarse or fine aggregate by quarry waste on the water absorption for solid cement bricks. The water absorption decreased by increasing the replacement percentage of natural coarse aggregate by quarry waste up to 100% replacement percentage. The decrease in the water absorption for 100% replacement percentage of coarse aggregate with coarse quarry waste was 45.9% compared with the control bricks. On the other hand, The water absorption decreased by using fine quarry waste up to 50% replacement percentage, then it increased by increasing the replacement percentage. The increase in the water absorption for 100% replacement percentage of fine aggregate with fine quarry waste was 7.3% compared with the control bricks.

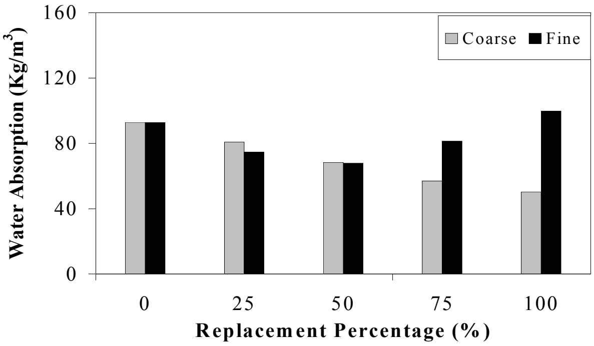

Figure 10. Effect of quarry waste on the water absorption of bricks

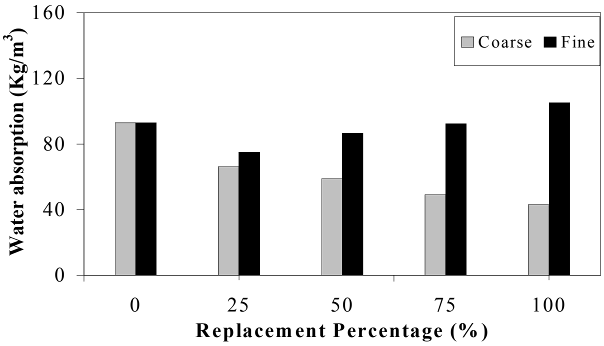

Figure 11. Effect of marble waste on the water absorption of bricks

Figure 11 shows the effect of replacement percentage of coarse or fine aggregate with marble waste on the water absorption for solid cement bricks. The water absorption decreased by increasing the replacement percentage of natural coarse aggregate by marble waste up to 100% replacement percentage. The decrease in the water absorption for 100% replacement percentage of coarse aggregate with coarse marble waste was 53.7% compared with the control bricks. On the other hand, the water absorption decreased by using fine marble waste up to 25% replacement percentage, then it increased by increasing the replacement percentage. The increase in the water absorption for 100% replacement percentage of fine aggregate with fine marble waste was 13.2% compared with the control bricks.

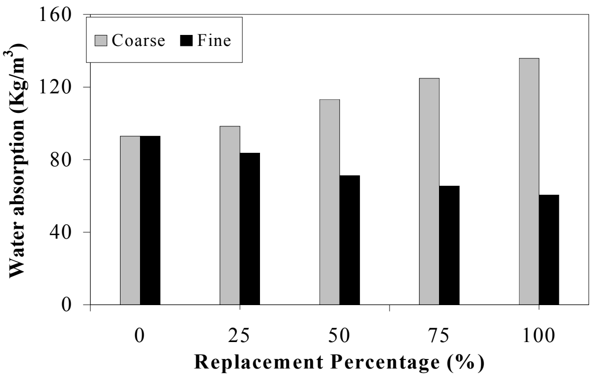

Figure 12. Effect of crushed ceramic on the water absorption of bricks

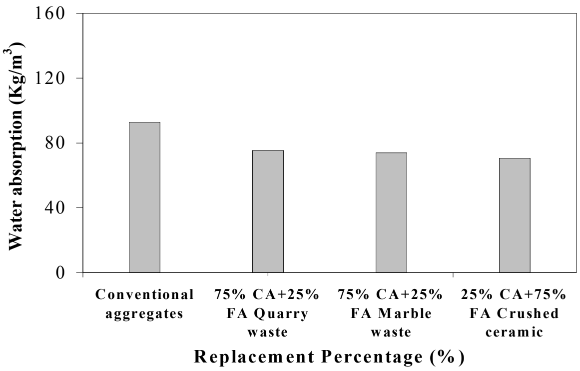

Figure 13. Effect of recycled aggregate type on the water absorption of bricks

Figure 12 shows the effect of replacement percentage of either coarse or fine aggregate by crushed ceramic on the water absorption for solid cement bricks. In general, the water absorption of solid cement bricks containing coarse crushed ceramic increased by increasing the replacement percentage of crushed ceramic up to 100%, while the use of fine crushed ceramic decreased the water absorption of bricks. The increase in the water absorption for bricks containing 100% coarse crushed ceramic was 46.2%, while the decrease in water absorption of bricks containing 100% fine crushed ceramic was 34.9% compared with the control bricks.

Figure 13 shows the effect of recycled aggregate type on the water absorption of solid cement bricks. As stated previously that the mixes presented in this figure includes the control mix and mixes including recycled aggregates (quarry waste, marble waste and crushed ceramic) replacing coarse and fine aggregates simultaneously. The percentages of fine and coarse recycled aggregates in these mixes are 75% and 25%, respectively for either quarry waste or marble waste, and 25% and 75%, respectively for crushed ceramic. The water absorption values for solid cement bricks containing recycled aggregates (quarry waste or marble waste or crushed ceramic) as coarse and fine aggregates were *lowest than that for the control bricks produced with conventional aggregates. The use of quarry waste, marble waste and crushed ceramic as fine and coarse aggregates simultaneously decreased the water absorption of bricks by 18.8%, 20.5% and 24% respectively compared with the control bricks.*

CONCLUSIONS

- *Recycling of wastes in solid cement bricks-making will lead to greener environment as it can be used to partially/totally replace coarse and fine aggregate.*
- *In general, the recycling of quarry waste, marble waste, or crushed ceramic as aggregate in solid cement bricks can provide a product with superior physical and mechanical properties than that produced with conventional aggregates on condition that selecting the suitable size of the waste (coarse or fine).*
- *In general, recycling quarry and marble wastes as coarse aggregates in solid cement bricks is better than using them as fine aggregate on contrary to crushed ceramic.*
- *The replacement percentage of conventional aggregates in cement bricks depends mainly on the type of the used waste (quarry waste, marble waste, or crushed ceramic).*
- *Quarry and marble waste can be used to replace up to 75% and 100% of coarse aggregate, respectively, or up to 50% of fine aggregate to produce bricks suitable for load bearing units, while crushed ceramic can be used to replace up to 100% of coarse or fine aggregate to produce bricks suitable for load bearing units.*

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