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## Enhancing of Crushed Brick Aggregate Concrete by Adding Alkalis

**Abstract-** *The process of recycling the waste of construction materials increased in most countries in the world, because of the huge quantities of waste materials result from demolition that will effect of the environment and increase landfills. This research aims to examine the recycle clay bricks aggregate in concrete mix instead of coarse aggregate and to study the effect of alkalis on this kind of concrete by partial replacement of recycle clay bricks aggregate (RCBA) instead of natural coarse aggregate. A cubic, cylinder and prisms specimens were casted to estimate the mechanical properties like dry and wet density, compressive strength, splitting tensile strength and modulus of rupture for this concrete. The results shows the increasing of RCBA will decrease the compressive strength, splitting tensile strength and modulus of rupture but the addition of alkalis with 20% of mix water will increase the workability and reduce the mix water and increase the wet and dry densities, and reduce the compressive strength and splitting tensile strength and the modulus of rupture.*

**Keywords-** *Alkalis addition; recycled brick aggregate concrete; compressive strength; splitting tensile; modulus of rupture.*

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### 1. Introduction

In the last decades, due to the demolishing of the old buildings, a concern has been growing how to make use of these materials as construction materials, which they are merely left in the landfill. Environmental impact can be reduced by making more sustainable use of these waste materials [1].

At present about 10% of bricks taken from demolition location being used as construction material (fine and coarse aggregates) while 90% of recycled concrete has been used as construction material this because of the lack of researches in this field and because of the high absorption of water and low compressive strength of broken brick aggregates compared to the conventional aggregate [2]. Waste managing means how to make use of these materials, which is result in lowering the overall coast of construction and reducing the environmental impact [3].

Waste brick can be used as construction material when it is separated and crushed into fine particles. It could be used in concrete mixtures. Nowadays, sustainable buildings have been used extensively because of large volume of recycle materials.

Concrete is one of the most material that is used for recycling the demolishing materials, majority of buildings are constructed from concrete around the world so the widely use of demolishing materials as an aggregate in concrete, a large

quantities of waste materials could be recycled [5].

Khalaf, and De Venny [6], present an experimental study about the effects of elevated temperatures on the properties of concrete made with crushed clay bricks instead of natural coarse aggregate. The study was done on two types of brick of different strength bricks to produce a different strength concrete. In addition, a natural granite aggregate has been used to produce concrete for the comparison, the results showed that crushed bricks could be used to produce concrete at high temperatures and the quality of concrete been similar and even better than granite concrete. Nevertheless, there are some questions regarding the behavior of concrete produced with ceramic wastes as aggregate.

Cachim [7] investigate the effect of the replacement of natural coarse aggregate by using two types of crushed clay bricks aggregate. The properties investigated were the density, workability of fresh concrete, the compressive strength, splitting tensile strength, modulus of elasticity and stress strain behavior of hardened concrete. Different replacement ratios were investigated as well as different water/cement ratios. The results of concrete produced with recycled aggregates were compared with a reference concrete produced with natural limestone aggregates. The results observed were that the resulting strength of concrete with bricks indicates the possibility of using this type of concrete in different precast applications.

Fadia [8] uses the crushed clay brick to substitute the coarse aggregate natural (gravel) in concrete. Two types of concrete are prepared. The first is a mixture of 1:2:4 without adding crushed clay brick aggregate to the mix and the second is made of different replacement of crushed brick from the coarse aggregate (0, 25%, 50%, 75%, and 100%). Cubes of (150 x150) mm and cylinders of (150 x300) mm are casted, tested for compressive stress, and split tensile stress. The result indicates that using crushed clay brick aggregate reduced the concrete strength, and increased the water content in the mix for constant slump when the clay brick aggregate percentage increased.

The use of alkali in cement mortar and concrete mix began since (1943) by Burrows [9,10] a long period study was made on 104 concrete panels that were casted using 27 different kinds of cements, then were placed in 1943 at Green Mountain dam in Colorado. Fifty- three years later, he found that the percentage of cracking on these panels was directly proportion to the alkali content in the cements used, that means that as the alkali content increases, the more drying shrinkage occurs. A lot of work has been done on cement mortar contains alkali, the results showed that as the alkali content in cement mortar increases the ultimate strength decreases correspondingly [11,12]. Blaine et al. [13] investigated a 199 commercial Portland cements, he tested large number of concrete specimens after 14 days curing, and the results revealed that the higher cement alkali content increases the dynamic modulus of elasticity. Osbaeck [14] in his study investigated the effect of alkali content on the development of strength and the ultimate strength. The results showed that a higher content of alkali in cement increase the development of strength and decreases the ultimate strength correspondingly. Jawed and Skalny [11] studied the effect of alkali on compressive strength of concrete, they showed that a high alkali content in cement increases the strength at early stages and then lower the strength after 28 days age. Gouda [15] studied the development of strength for different alkali content specimens; low-alkali (0.58% NaOH) and high-alkali (1.76% NaOH) were tested at 7 days. A low cement alkali content can result in very low strength developments at early ages [16]. Whilst Odler et al. [17] investigated the alkalis included into the cement clinker. The results showed that addition of alkali into cement clinker does not affect the compressive strength while the addition of alkali sulfate reduces the compressive strength at any period up to 28 days. Alexander and Davies [18] studied the effect of alkali on cement mortar.

They found that addition of alkali to cement mortar decreases the compressive strength, whereas the modulus of rupture increases.

Smaoui [9] studied the addition of alkali to the concrete mix, he found that the addition of alkali has harmful effects on mechanical properties of concrete which cause reduction in (splitting tensile, direct tensile, compressive, and flexure) strengths, but do not affect the elastic modulus.

The effects of using alkalis in concrete are still not very well understood, because: (1) Majority of experimental studies done on cement mortar specimens. (2) To show the effect of the different alkali contents the researchers used cement with different alkali content instead of adding NaOH to the mix. (3) The mechanical property investigated in was the compressive strength and the drying shrinkage. The work done concerning freezing–thawing durability is very limited.

The use of NaOH in recycle aggregate concrete began with concrete with recycle tier rubber by replacement of mortar sand by recycle rubber [19,20]. The improvement in strength is due to the increasing of roughness of rubber due to treating by alkali materials. This increase of roughness will lead to improve the adhesion force between rubbers and cement mortar.

This study is designed to evaluate the effect of replacing natural coarse aggregate by crushed bricks aggregate and the effect of alkalis addition (NaOH) on this concrete containing different replacement of recycle brick aggregate. Then, study the effect of alkalis on some of concrete properties, which includes wet and dry densities and strength development (compressive strength, split tensile strength, flexural strength (modulus of rupture)).

## 2. Experimental Works

### I. Materials

1. Cement: Iraqi standard ordinary Portland cement has been used. The chemical analysis and mechanical properties of this cement is shown in Table 1.

**Table 1: The chemical composition and mechanical properties of cement**

Compound	N0.	Specification <sup>[21]</sup>
Insoluble	0.96	Not more than 1.5
SiO <sub>2</sub>	13.8	Not more than 21
Al <sub>2</sub> O <sub>3</sub>	0	-----
Fe <sub>2</sub> O <sub>3</sub>	0	Not more than 6
MgO	0	Not more than 5
SO <sub>3</sub>	1.18	Not more than 2.5
C <sub>3</sub> A	5.2	Not more than 8
Loss on ignition	0.89	Not more than 4
3 day compressive	20.3	Not less 15 N/mm <sup>2</sup>

strength (N/mm <sup>2</sup> )		
Initial setting (min.)	52	Not less 45 min
Final setting (min.)	510	Not less 10 hours
Fineness(Kg /m <sup>2</sup> )	299.75	Not less 250 kg/m <sup>2</sup>

2. Fine aggregate: Natural sand from Al-Tuz city has been used as fine aggregate. The grading of this sand is according the B.S. 882. 1973 [22] as shown in Table 2. The chemical composition is given in Table 3.

3. Coarse aggregate

Natural gravel: Local river gravel from Al-Tuz city has been used. The grading of the natural gravel is within the limits of British Standard (B.S.882:1973) [22] as shown in Table 4.

Crushed brick: clay brick obtained from demolished waste have been crushed by steel hammer to maximum size of (20 mm) which similar to the grading of the natural gravel aggregate. The specific gravity of brick aggregate is 2 and the absorption is 17.5 % of dry weight.

Alkaline: NaOH 0.1 M, pH= 13.9. which is add to the mixing water by a percent of 20% from the weight of water.

**Table 2: Grading of sand**

Sieve No. mm	Natural sand passing %	passing % range according to B.S. 882:1973[24]
9.5	100	100
4.75	95.5	90-100
2.36	86	75-100
1.18	65	55-90
0.600	54	35-59
0.300	21	8-30
0.150	3.5	0-10
0.075	0.25	0
pan	0	0

**Table 3: The chemical composition of sand**

Test	N0.	Specification <sup>[25]</sup>
% of granular material	0.2	less than 0.5
% Total salt	7	less than 5
	6	
% other material	0	less than 2

**Table 4: Grading of gravel**

Sieve No. mm	Natural gravel passing %	passing % range according to B.S. 882:1973 <sup>[24]</sup>
20	85	85-100
9.5	15	0-25
4.75	0	0-5
0.150	0	0
pan	0	0

The chemical composition is given in Table 5.

**Table 5: The chemical composition of gravel**

Test	N0.	Specification <sup>[25]</sup>
% of granular material	0.0089	0.1%
% soluble salt	0.041	5%
% peat	0	2%

**3. Mix Design**

The mix proportion designed by weight of the constituents is cement: fine aggregate: coarse aggregate: water/cement ratio 1.0:1.5:3.0:0.45, while the natural coarse aggregate has been replaced in suitable with recycled brick aggregate (0%, 30%, 50%, 70%, 100%). Two kinds of concrete mix used in this study: the first is by using recycled brick aggregate without alkalis and the other is by using recycled brick aggregate with alkalis (adding NaOH to the mixture water percent of 20%weight of water). The water – cement ratio has been chosen for concrete mixes with recycle concrete aggregates to obtain the slump ranging (80-100) mm.

A total of 80 numbers of concrete specimens (a cube of ( 150 x150) mm and cylinder of (100 x 200) mm and a serious of prisms of (100 x100 x 500) mm are casted with concrete mix to determine their compressive , Splitting Tensile and flexural strength for 28 days.

In this experimental study found the broken brick aggregate is lighter than the natural gravel so it occupies larger volume than that of the natural gravel for the same weight, so the quantity of water in the mix will be more. Water – cement ratio has been chosen for concrete mixes with recycle crushed brick aggregates to obtain the slump range (80 - 100) mm.

When adding the NaOH addition, the w/c ratio remains the same for all mixture for different replacement of (RCBA) and increase the workability.

The concrete has been molded into cylindrical mold in four equal layers and into cubic mould in three equal layers and for prisms in two equal layers and compacted using a vibrating table.

The specimens have been covered with a plastic and kept in the laboratory for 24 hours after that they were demolded and cured in water for 28 days until the time of testing.

**4. Details of the Experimental Study**

*I. Strength of Concrete*

a) Compressive strength

Cubes specimens are used for compression strength test. The test program consisted of total 30 cube of 150 mm side. (15 cubes without alkalis and 15 with addition of alkalis) .Concrete cubes has been tested according to B.S.1881, part

(116) [23]. A compressive machine (Wecabe) of 2000 kN capacity has been used to perform this test. Three cubes specimens have been used to determine the average of compressive strength at 28 days curing date.

b) Splitting tensile strength

The splitting tensile strength is tested on cylinder specimens. The test program consisted of 30 specimens for tensile strength test (15 cylinders without alkalis and 15 with addition of alkalis). The average of three specimens is taken. The splitting tensile strength is carried out according to ASTM C496-90 [24]. The splitting tensile strength has been calculated as follows:

$$F_t = \frac{2P}{\pi d l} \tag{1}$$

Where:

$F_t$ = splitting tensile strength (N/mm<sup>2</sup>)

$P$ = maximum applied load, (N)

$l$ =length, (mm)

$d$ = diameter, (mm)

c) Modulus of rupture

The modulus of rupture is determined by testing standard test specimen of 100 mm × 100 mm × 500 mm, under symmetrical loading. The test program consist of 20 prisms for modulus of rupture test (10 prisms without alkalis and 10 with addition of alkalis). The modulus of rupture is determined by the movement at failures as:

$$F_r = \frac{3PL}{2 b d^2} \tag{2}$$

(2)

Where:

$F_r$  = modulus of rupture.

$P$  = failure load.

$L$  =2/3 length of prism.

$B$  = width of prism.

$D$  =height of prism.

5. Results and Discussion

I. Air dry density

a. Dry density of concrete

Figure 1 shows the test results of air dry density of RCBA concrete (without and with) using alkalis as addition using RCBA instead of normal aggregate in concrete reduces the dry density from (2395-1792) kg/m<sup>3</sup> due to the light weight of the recycle clay brick aggregate than the normal aggregate, but adding NaOH increases the dry density of concrete from (2398-2002) kg/m<sup>3</sup>.

II. Wet density

Figure 2 shows that the test results of wet density of RCBA concrete (without and with) using

alkalis as addition. It is clear that using RCBA instead of normal aggregate in concrete reduces its wet density from (2262-1765) kg/m<sup>3</sup>, but adding NaOH increased the wet density for concrete from (2349-1925) kg/m<sup>3</sup>.

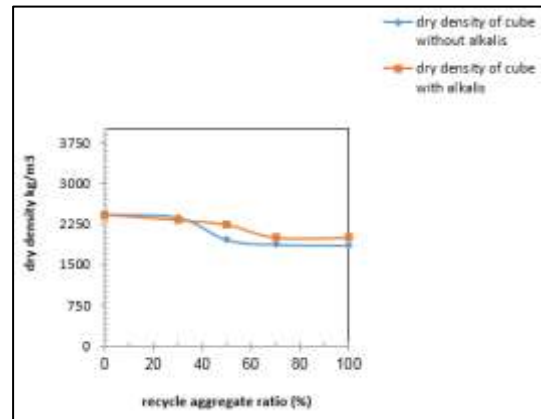


Figure 1: Influence of using recycle aggregate on dry density of RCBA concrete (with and without alkalis)

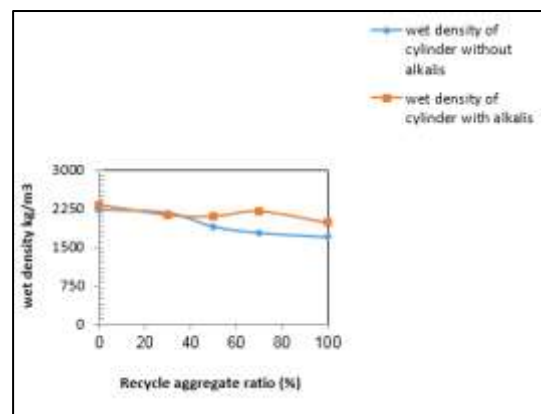


Figure 2: Influence of using recycle aggregate on wet density of RCBA concrete (with and without alkalis)

III. Compressive strength

Figure 3 shows that the test results of compressive strength of cube specimens of RCBA concrete (without and with) using alkalis as addition the results indicated the mean of 3 samples at 28 days. The figure shows that using the RCBA in concrete reduces its compressive strength. The reduction is (75) %, but adding NaOH will also reduce compressive strength of cubes less than (73.6) %.

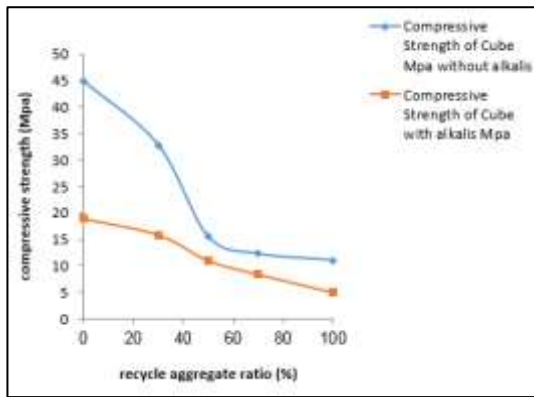


Figure 3: Influence of using recycle aggregate on compressive strength of cube (with and without alkalis)

IV. Splitting tensile strength

Figure 4 shows that the test results of splitting tensile strength of cylinders specimens with RCBA concrete (without and with) using alkalis as addition are the mean of 3 specimens at the age of 28 days. It is clear that using the RCBA in concrete reduces its Splitting tensile strength of cylinders less than (90.8) %, but adding NaOH will also decrease Splitting tensile strength of cylinders from (0-50)% RCBA and increases splitting tensile strength of cylinders when using (70 -100) % RCBA.

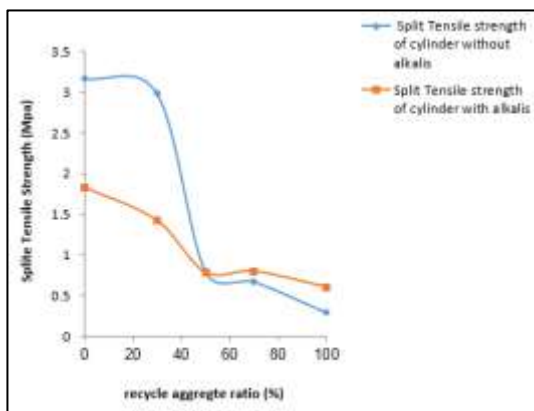


Figure 4: Influence of using recycle aggregate on split tensile strength of cylinder (with and without alkalis)

The reduction in (compressive and tensile) strengths because:

- I. The broken bricks aggregate adding to the concrete instead of natural aggregate does not make adequate bond with concrete and cement matrix.
- II. Due to the high porosity of the surfaces of the concrete with broken bricks aggregate, the mix needs more water to reach the required slump.
- III. The broken bricks aggregate reduces the workability because of roughness of the

surfaces of broken bricks aggregates affecting the compaction distribution upon the concrete layers.

IV. The addition of alkalis leads to repulsion between it and cement which results in slowing of sedimentation of cement. As a result increasing the workability of concrete but decreasing the compressive strength.

V. Modulus of rupture

Figure 5 shows that the test results of modulus of rupture of prisms specimens of RCBA concrete (without and with) using alkalis as addition are average of 2 specimens at the age of 28 days.

From this figure, it is clear that using the RCBA in concrete reduces its modulus of rupture. The reduction is from (45.5) % but adding NaOH will also decrease modulus of rupture from (45.7) %.

The recycle clay brick aggregate is lighter than the natural aggregate so its occupies more volume than the natural aggregate for the same weight, so that more water required for these mixtures with recycle clay brick aggregate. Increasing recycle clay brick aggregate ratio leads to increasing water cement ratio. Figure 6 shows the relation between the ratio of recycle clay brick aggregate and w/c ratio of RCBA concrete (with and without) using alkalis. The w/c will increase from (0.45 - 0.65) for concrete without NaOH, but when adding NaOH as addition to the concrete mix the w/c ratio the same different ratio of recycle clay brick aggregate.

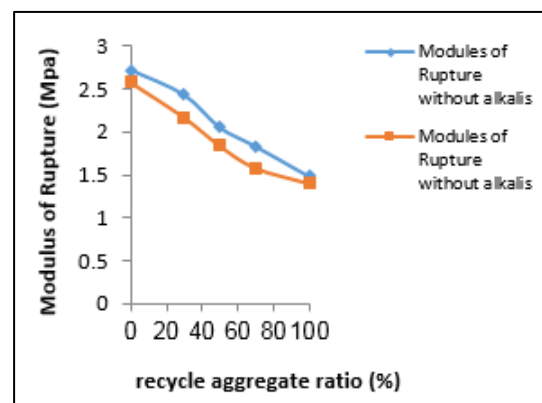
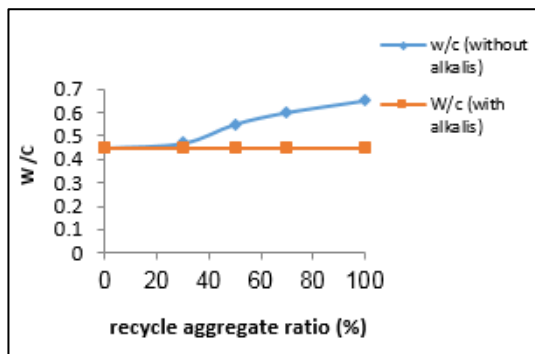


Figure 5: Influence of using recycle aggregate on modulus of rupture (with and without alkalis)



**Figure 6: Influence of using recycle aggregate on W/C of RCBA (with and without alkalis)**

## 6. Conclusions

Based on the experimental results of compressive and split tensile strength and modulus of rupture of concrete the following observations are made:

- Unit weight of RCBA is lower than that of natural gravel aggregate in condition, which, contributes to the decrease in the unit density of concrete containing RCBA as coarse aggregate and that will be from the lightweight concrete.
- From the obtained results, we observe that the maximum strength is achieved by 30% of RCBA replacement in concrete. The 30th% of RCBA replacement in concrete indicates that there is no strength gaining after increasing the proportion.
- The compressive strength of partial replacement of RCBA concrete is marginally lower than that of the natural gravel aggregate concrete at age about 75%.
- The split tensile strength of partial replacement of RCBA concrete lower than that of the natural gravel aggregate about 90.8%.
- The modulus of rupture of partial replacement of RCBA concrete is marginally lower than that of the natural gravel aggregate concrete.
- The benefits of using the alkalis in RCBA in concrete to increase the workability and reduce the w/c ratio for the same percent of RCBA.
- Using alkalis in RCBA concrete will increase the wet and dry density and reduces compressive strength and split tensile strength.
- Using alkalis in RCBA concrete has small effect on modulus of rupture.

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