Effect of Recycled Aggregate on Interlocking Concrete Blocks for Paving Aircraft Parking Areas in Iraq

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Abstract - *This study aims to produce interlocking concrete blocks and base coarse by using recycled concrete aggregates which obtained from construction and demolition (C & D) wastes. As well as improving the subgrade layer using cement kiln dust (CKD) in order to construct pavement for aircraft parking area in Iraq. The work in this study includes laboratory tests to check the suitability of recycled concrete aggregate. Three concrete mixes have been prepared and tested (the first concrete mix without any additives or super plasticizers, the second concrete mix with 20 % cement kiln dust (CKD) as an addition to cement weight, and the third concrete mix with 20% cement kiln dust (CKD) as an addition to cement weight and super plasticizer (PC200)). Each concrete mix contains five groups with various proportions of RCA (0%, 25%, 50%, 75%, and 100%) in order to find best group that gives the higher compressive strength and to find the appropriate percentage of natural aggregate replacement to casting three different shapes of interlocking concrete blocks (rectangular, square and L shape). The subgrade layer for aircraft parking must be stiffened enough to withstand the static load of 230 KN. Therefore, the subgrade soil treated with 16% CKD as an additive to the weight of subgrade. The base course layer is prepared from conventional granular base material plus RCA material and stabilized by 3% and 5% cement. A laboratory simulation (box model) test has been carried out on interlocking concrete block pavement (ICBP) section to evaluate the ICBP performance by measuring deflection which has been used in back calculation program (BAKFAA) to find the elastic modulus of each layer. The results show that, RCA materials are suitable to use as aggregate materials in concrete mixes, the best concrete mix that is prepared with 20% of cement kiln dust (CKD) as an addition to cement weight and super plasticizers (PC200) which gives a compressive strength more than (40 MPa). The appropriate replacement percentages of NA by RCA are (25% and 50%). By means of elastic modulus, the best shape of concrete blocks is rectangular shape laying in 45°herringbone pattern.*

Keywords - *Concrete blocks, Recycled concrete aggregate, Deflection and Back calculation.*

I. INTRODUCTION

Development and population growth all over the world have led to a large development in transportation, which requires making the pavements with high-efficiency to carry the imposed loads. The civil aviation system, especially airports, considers the backbone of world transport and a necessity to twenty-first-century trade, commerce and travel. For this purpose, it became necessary to introduce and use of new ideas for design such as interlocking concrete block pavement with using some of the waste materials likes (concrete demolition wastes, cement kiln dust, etc.) that are helpful to reach the best results with less costs. Recycled demolition aggregate can be used to replace newly quarried limestone aggregate for production the paving blocks, and to be used as base and sub base materials [1], [2] and [3]. Also cement kiln dust can be used as stabilized materials for subgrade soil and concrete [4].

Where the aircrafts parking pavements are constructed to provide adequate support for the loads imposed by aircrafts, the pavement must be of such quality and thickness that it will not fail under the aircrafts load [5]. Designed and constructed, any pavement type (flexible, rigid, composite, etc.) can give a satisfactory pavement for any civil aircrafts. However, some designs may be more economical than others and still offer satisfactory performance. Rigid pavement is the preferred pavement for aircrafts parking, ramps and aprons but could not support expected subgrade settlement without severe distresses that could cut off airport operations. A flexible pavement is generally selected when there are working benefits or budget constraint. When compared to conventional asphalt or poured concrete, interlocking concrete block pavement meet these criteria for aircraft pavements [6].

Interlocking concrete block pavement (ICBP) in each design method, it has supposed that the pavers and their laying course materials take part to the strength of the pavement and that the material do in a similar way to a homogeneous elastic material. The use of (ICBP) on aircrafts parking pavements provides a compromise between the inherent problems associated with conventional flexible and rigid pavements; for many reasons [6]:

- Resistance to static loading
- A stable surface.
- Resistance to fuel, hydraulic oils and de-icing chemicals.
- Adequate skid resistance.
- Can be painted or colored unites used for pavement markings.
- Fast construction and reinstatement.
- Less costly reinstatement.
- Rapid removal of surface water and snow.

Otherwise, there are some problems associated with block pavement such as (block rotation, water penetration through the joints, and loss of jointing sand).

The main aim of this study is to check the structural behavior of interlocking concrete block pavement which contains recycled concrete aggregate as aircrafts parking and investigate the suitability of recycled concrete aggregate as alternative to the conventional coarse aggregate in concrete mixes with different percentages of replacement (0%, 25%, 50%, 75%, and 100%).

II. EXPERIMENTAL WORK

A. Materials

1) Soil: Soil used in this study as a subgrade material. Table (1) shows the physical properties of the soil sample which has been tested under Standard specification.

Table (1) Physical Properties of natural soil

Index property	**Standard specification**	**Index value**
Water Content %		8.7
Liquid limit % (L.L)	ASTM D4318 (A) [7]	32.63
Plastic limit % (P.L)	ASTM D4318	25.98
Plasticity index % (P.I)	D427 [8]	6.65
Specific gravity (Gs)	BS(1377)	2.65
% passing sieve NO.200	-----	50.2
Soil Symbols (USCS)	ASTM D2487 [9]	ML

2) Cement: Ordinary Portland cement (Type I) was used in this study. It was tested and checked according to Iraqi standard specification No.5 /1984, (IS 1984) [10]. Table (2) and (3) show the physical and chemical properties of cement.

Table (2) Physical properties of Portland cement

Physical properties	**Test results**	**Limits of Iraqi Standard specification No.5/1984[10]**
Specific gravity	3.24	……
Specific Surface Area (Blaine method) (cm^2/g)	3126	Not less that 230
Setting time-vicat's method, Initial (min)	104	Min. 45
Setting time-vicat's method, Final (hrs)	5.11	Max. 10
Soundness (autoclave)%	0.32	≤ 0.8
Compressive strength, (MPa) at 3 days	16.44	≥ 15
Compressive strength, (MPa) at 7 days	26.37	≥ 23

Table (3) Chemical composition of Portland cement

Chemical compound	**% Content**	**Limits of Iraqi Standard specification No.5/1984[10]**
CaO	62.27	-------
Sio_2	19.53	-------
Al_2O_3	5.68	-------
Fe_2O_3	3.05	-------
MgO	2.72	< 5
So_3	2.23	< 2.3
Loss of ignition (L.O.I)	3.11	< 4
Lime Saturation Factor (L.S.F)	0.91	0.66 – 1.02
C3S	55.84	-------
C2S	13.58	-------
C3A	9.89	-------
C4AF	9.27	-------

3) Aggregate: Crushed Natural Coarse Aggregate

The crushed natural coarse aggregate was tested according to (ASTM C136, 2004) [11]. Tables (4) and (5) had listed the physical properties and the gradation of coarse aggregate.

Table (4) Physical properties of crushed natural coarse aggregate

Physical properties	Test results	Limits %
Gsb Dry ASTM C 127 [12]	2.58	------
Absorption % (ASTM C 127) [12]	0.33	------
Sulfate content AASHTO T -290 [13]	0.079	< 0.1%
Organic impurities (AASHTO T-21) [14]	0.23	< 2 %
Gsb OD (ASTM C 127) [12]	2.54	------
Gsb SSD (ASTM C 127) [12]	2.56	------
Abrasion resistance % (ASTM C 131) [15]	12	Max. 35% by mass
Dry unit weight (g/cm^3) (ASTM C 29) [16]	1.6	-------

Table (5) Coarse aggregate gradation limits (ASTM C136, 2004) [11]

Sieve size (mm)	Cumulative passing %	Standard grading (ASTM C136, 2004) [11]
25	100	100
19	95	90-100
9.5	37	20-55
4.75	5	0-10
2.36	3.5	0-5

Fine Aggregate

The size of fine aggregate used in this study was between the size passing No.4 (4.75mm) sieve and retained on sieve No.200 according to (ASTM C33-04) [17]. Tables (6) and (7) show the physical properties and the gradation of fine aggregate. Also Tables (8) and (9) show the gradations for bedding and jointing sand according to (Specification 35, 2005) [18].

Table (6) Physical properties of sand

Physical properties	Test results	Limits
Gsb dry ASTM C 128, [19]	2.67	---------
Absorption % (ASTM C 128) [19]	0.58	---------
Fineness Modulus (F.M)	2.74	2.3-3.1
Sulfate content	0.08	< 0.5 %

Table (7) Grading of sand (ASTM C33-04) [17]

Sieve size (mm)	Cumulative passing (%)	Standard grading ASTM C33-04[17]
9.5	100	100
4.75	97	95 – 100
2.36	84	80 – 100
1.18	61	50 – 85
0.6	44	25 – 60
0.3	27	10 – 30
0.15	3.5	2 – 10

Table (8) Grading of bedding sand (Specification 35, 2005) [18]

Sieve size (mm)	Cumulative passing (%)	Standard grading
9.5	100	100
4.75	97	95 – 100
2.36	88	80 – 100
1.18	65	50 – 85
0.6	40	25 – 60
0.3	17	5 – 30
0.15	5	0 – 10
0.075	0.5	0 – 1

Table (9) Grading of jointing sand (Specification 35, 2005) [18]

Sieve size (mm)	Cumulative passing (%)	Standard grading
2.36	100	100
1.18	95	90 – 100
0.6	65	40 – 95
0.3	25	12 – 40
0.15	5	0 –10
0.075	1	0 – 2

Recycled Concrete Aggregate (RCA)

The Recycled Concrete Aggregate (RCA) has been collected from waste materials, by crushing concrete cubes using jaw crusher machine. Tables (10) and (11) show the physical properties and the gradation of this aggregate.

Table (10) Physical properties of recycled concrete aggregate (RCA)

physical properties	Test results	Iraqi specification limits No.45/ 1984 [10]
Gsb Dry (ASTM C 127) [12]	2.53	--------
Absorption % (ASTM C 127) [12]	5	--------
Gsb OD (ASTM C 127) [12]	2.42	--------
Gsb SSD (ASTM C 127) [12]	2.49	--------
Abrasion resistance % (ASTM C 131) [15]	24	Max. 35% by mass
Dry Unit weight (g/cm3)(ASTM C 29) [16]	1.42	--------

Table (11) Recycled concrete aggregate gradation limits (ASTM C136, 2004) [11]

Sieve size (mm)	Cumulative passing (%)	Standard grading (ASTM C136, 2004) [11]
25	100	100
19	95	90-100
9.5	37	20-55
4.75	5	0-10
2.36	3.5	0-5

4) Cement Kiln Dust (CKD)

Cement Kiln Dust (CKD) is a by-product material generated in the Portland cement production. The CKD used in this work is produced from New Kufa Cement Plant as waste material. It passes through a sieve of size (0.15 mm). Table (12) shows the chemical properties of CKD used in this study.

5) Super Plasticizers (PC200)

Hyper plastic (PC200) is a high performance super plasticizing admixture. This additive can be used to achieve highest concrete durability and performance. It complies with ASTM C494, type A and G, depending on dosage used [20]. Table (13) shows the properties of PC200.

Table (13) Typical properties of super plasticizers

Technical properties at 25 °C	
Color	light yellow liquid
Freezing point	≈ - 3 °C
Specifice gravity	1.05 ± 0.02
Air entrainment	typically less than 2% additional air is entrained above control mix at normal dosage

B. Model Preparation

1) Subgrade Soil Layer

The moisture – density relation for subgrade layer is determined using modified compaction. The compaction is carried out in five layers with 25 blows / layer using 10 Ib (4.54 kg) hammer with drop of 18 in (457.2mm) according to method (A) of (ASTM D 1557, 2013) [21]. On the other hand, the moisture content is performed in accordance to (ASTM D 2216, 2005) [22].The California Bearing Ratio Test (CBR) has been used to find the strength of the subgrade layer. For this test, three samples are prepared from the natural soil and three samples are prepared by adding 16% CKD as stabilizer material to the natural soil according to (EGBE, 2012) [23] to improve the strength of the subgrade layer.

2) Cement Stabilized Base Course

The base course of aggregate (coarse, fine and filler) for conventional materials and non-conventional materials (Recycled Concrete Aggregate RCA) are prepared to confirm the selected gradation requirements of SCRB specification for base coarse (SCRB, 2003) [24] as shown in table (14). After that, the base course of aggregate from conventional materials and Recycled Concrete Aggregate (RCA) treated with 3% and 5% cement as stabilized materials. From each mix, samples prepared to find Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and Unconfined Compressive Strength (UCS). The compaction test of base coarse performed according to (ASTM D1557) [21] and the moisture content determinations are performed according to (ASTM D2216, 2005) [22]. Also, the Unconfined Compression Strength Test (UCS) performed according to (ASTM D1633, 2000) [25].

Table (12) Chemical properties of CKD

Composition	SiO_3	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	L.O.I.	chlorides
Percent	15.46	3.41	3.05	43.4	2.98	6.34	2.44	1.42	28.86	0.92

Table (14) Gradation of the aggregate for base course (SCRB, 2003) [24]

Sieve size (mm)	Cumulative passing (%)	Specification limit (SCRB)
37.5	100	100
25	95	80 – 100
12.5	70	50 – 80
4.75	47	30 – 60
0.45	22	10 – 30
0.075	10	5 – 15

3) Mix Proportions of concrete

The prime goal in this study is to choose the best mix that gives the highest compressive strength, as well as choose the appropriate percentage of replacement of natural aggregate by recycled concrete aggregate in concrete mix. Therefore, three concrete mixes used in this study, the first mix is conventional mix without any additives (cement Kiln dust (CKD)) or super plasticizers, the second mix is prepared with 20% cement kiln dust (CKD) as an addition to cement weight and the third mix is prepared with 20% CKD as an addition to cement weight and (PC200) as super plasticizers. Table (15) shows the concrete mix proportions of (1) m^3 according to (ACI 211.1) [26]. All the mixes have been prepared for slump of 15-100 mm and air content of 0.015 per unit volume.

To determine the compressive strength of hardened concrete at 7 and 28 days age, the samples are prepared for each of concrete mixes, as shown in Table (16).

The mix which has the highest compressive strength will be adopted to manufactured different shapes of concrete blocks (rectangular 200 mm x 100 mm, square 150 mm x 150 mm and L shape 200 x 100 mm) with constant thickness of 80 mm, as shown in Figure (1). Table (17) shows the total number of concrete blocks which prepared from each form of replacement in concrete mix.

Table (15) Mix proportions of all mixes for (1) m^3

Mix	Cement (kg)	Sand (kg)	Natural coarse agg. (kg)	Recycled coarse agg. (kg)	Water (kg)
Mix A	460	675	1080	------	192
Mix B	460	675	810	270	192
Mix C	460	675	540	540	192
Mix D	460	675	270	810	192
Mix E	460	675	------	1080	192

Note: Mix A, the first form: 0% replacement. Mix B, the second form: 25% replacement. Mix C, the third form: 50% replacement. Mix D, the fourth form: 75 % replacement. Mix E, the fifth form: 100% replacement.

Table (16) Number of cubic concrete samples

Concrete mixes	Test	Samples	Number of cubes	
			age 7 days	age 28 days
Conventional mix	Compressive strength	Cubes 150x150x150 mm	15	15
Mix with 20% CKD			15	15
Mix with 20% CKD & PC200			15	15

Figure (1) Samples of interlocking concrete blocks

4) Fresh and Hardened Concrete Tests

Workability

Slump test performed for the measurement of the fresh concrete workability. This test is performed in accordance to (ASTM C143, 2004) [27].

Density

The concrete density has been calculated by dividing the weight of each concrete sample on the sample volume.

Compressive Strength Test

The compressive strength test was carried out on (150x150x150) mm cubes using a digital compression machine of 200 kN capacity. The load applied at a rate of 1.5 kN/sec. accordance with (BS1881/part108, 1983) [28]. The average value of three tested cubes was adopted at each testing age (7 days and 28 days age)

Table (17) Number of concrete block samples

	Concrete blocks	Dimension mm	Test	Number of samples
Each form of replacement 0%, 25%, 50%, 75% and 100%	Rectangular	200x 100	Compressive strength at age of 28 days	3 for each form (total 15)
	Square	150x 150		3 for each form (total 15)
	L Shape	200x 100		3 for each form (total 15)

Ultrasonic Pulse Velocity Test

This test covers the calculations of the propagation velocity of longitudinal stress wave pulses through concrete, using the portable ultrasonic non-destructive digital device. Figure (2) shows the test set up.

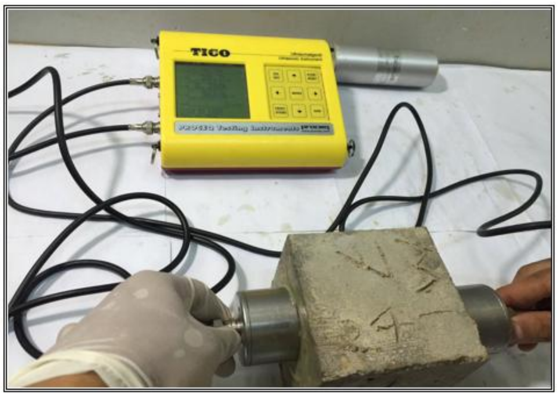

Figure (2) Ultrasonic pulse velocity test set up

Pulses of longitudinal stress waves are produced by an electro-acoustical transducer that caught in contact with one surface of the concrete under test. After crossing through the concrete, the pulses are received and transformed into electrical energy by a second transducer existing a distance L from the transmitting transducer. The transit time T is measured electronically. The pulse velocity V is determined by dividing L by T. This test is important to determine the mechanical strength of concrete. The test is carried out in accordance with ASTM C597, 2002 [29].

C. Deflection Test

The laboratory simulation (box model) test has been carried out on Interlocking Concrete Block Pavement (ICBP) section to determine ICBP performance and measure the deflection of each layer of the model. The deflection values will be used later to determine the elastic modulus of layers by back calculation procedure. The test is carried out by applying a static load using compression testing machine to make it similar to the FWD test. The values of load are suggested depending on the load applied by aircraft B747-400 according to (Bikasha C. and Ashok K., 2002) [30].

1) Steel Box

The test is carried out by applying a static load using compression testing machine. A steel box is used in this study with the internal dimensions 460 mm x 460 mm square in plan and 1100 mm depth. The section of interlocking concrete pavers is constructed within the test box. A piston system is with two ends, the top one is a square plat 450 x 450 mm fitted with a hydraulic jack of compression testing machine by bolts, and the bottom one is a rigid circular plate of diameter 250 mm, this diameter corresponds to the tire contact area used in pavement analysis to apply a central load to the pavement, as shown in Figure (3). The adjacent edges of a steel box act as edge restraints. The pavement's deflection is measured using a deflection gauge to an accuracy of 0.01 mm corresponding to the load. The load is increased in 2.5 kN or 5 kN increments from zero. The deflection gauge readings are taken at each load increment. The gauge is placed on the side of the plate at a distance 125 mm from the center of loading plate. The structural design of the pavement in this test is the same design for Dallas/Fort worth (DFW) International Airport, Dallas, Texas by using 80 mm thickness of rectangular concrete pavers placed in herringbone pattern, 25 mm of bedding sand, 685 mm cement treated base (CTB) and 300 mm subgrade (Patroni J. F., 1995) [31]. Parameters such as block shape and laying pattern vary in experimental work. For each variation of parameter, the test is performed.

Figure (3) Steel box and Piston system

2) Subgrade Deflection Test

The subgrade used in this test is a natural soil with 16% CKD as stabilizer material to improve the properties of soil. The subgrade's elevation is 300 mm which placed in two layers; each layer is 150 mm and compacted at optimum moisture content. A maximum load of 40 kN is applied to the subgrade. This load was chosen as mentioned by (Haradhan et al., 2014) [32]. The subgrade deflection is measured using deflection gauge to an accuracy of 0.01 mm corresponding to load of 40 kN. The load is in 2.5 kN increments from 0 to 40 kN. The deflection gauge readings are taken at each load increment.

3) Base Course Deflection Test

The base course, used in this study is prepared according to the SCRB specification, as mentioned above. The base course elevation is 685 mm above the subgrade layer, the base is placed in four layers, 200 mm, 200 mm, 150 mm and 135 mm respectively and compacted at optimum moisture content. A maximum load of 110 kN is applied in 5 kN increments from 0 to 110 kN, this load was chosen as mentioned by (Haradhan et al., 2014) [32]. The base deflection is measured using deflection gauge to an accuracy of 0.01 mm. The deflection gauge readings are taken at each load increment.

4) Interlocking Concrete Block Deflection Test

Three shapes of concrete blocks (rectangular, square and L shape) with 80 mm thickness are used for deflection test with various laying patterns as shown in Figure (4). The pavers are placed on 25 mm of bedding sand above the beneath layers (base and subgrade). Pavers are placed manually on bedding sand and the joints are filled with jointing sand. The joint filling process is continued until all joints are fully filled with sand. Finally, the top surface of the pavement cleaned of excess sand. A maximum load of 230 kN is applied on the concrete pavers. This load is suggested depending on the load applied by aircraft B747-400. The load applied on the concrete pavers for different shapes and laying patterns for the comparison purpose. The pavers' deflection is measured using deflection gauge to an accuracy of 0.01 mm corresponding to load of 230 kN. The load is in 5 kN increments from 0 to 230 kN. The deflection gauge readings are taken at each load increment.

Figure (4) Various shapes of pavers and laying patterns

III. TEST RESULTS and DISCUSSION

A. Test Results for Subgrade Layer

Table (18) and Figure (5) show the compaction characteristics of the tested soil. The maximum dry unit weight is (1.98 g/cm^3) with optimum moisture content of (12.67%).

Table (18) Moisture-Density values for subgrade soil

Water content (%)	Dry unit weight (g/cm³)
8.03	1.88
9.64	1.94
12.67	1.98
13.52	1.95
15.67	1.85

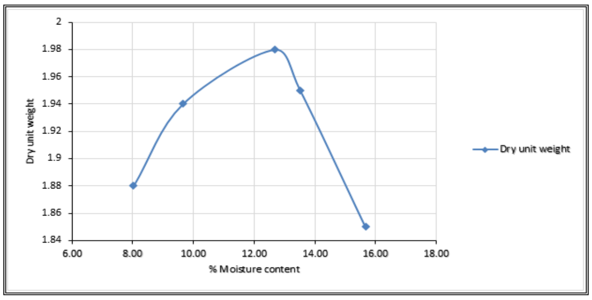

Figure (5) The Moisture-Density relationship for subgrade soil

Figures (6) to (9) show the results of CBR test for natural subgrade soil and stabilized subgrade soil with 16% CKD. The results show that, the CBR value of stabilized subgrade soil with 16% CKD was higher than the values of natural subgrade soil. This could be related to the amount of dust materials which are contained with particles of portland cement that have more resistance to the applied load as compared with the natural subgrade soil.

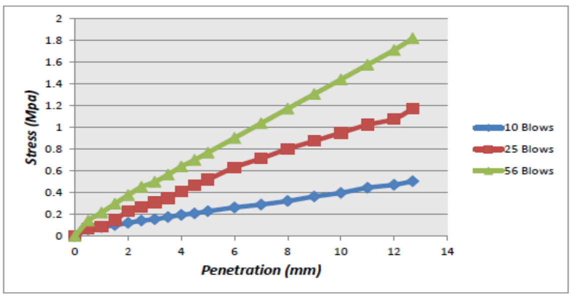

Figure (6) Stress-Penetration relationship for natural subgrade soil

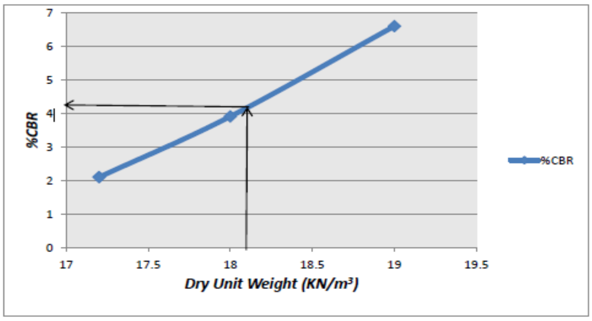

Figure (7) Relationship between CBR and dry unit weight for natural subgrade

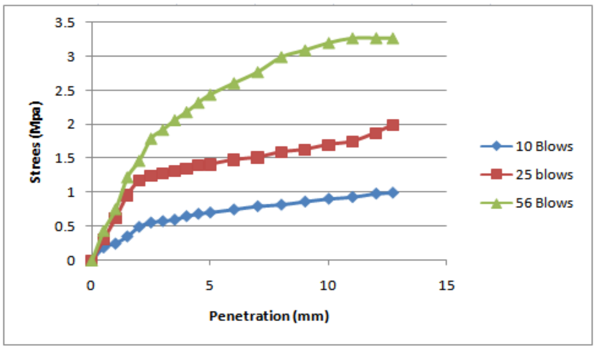

Figure (8) Stress-Penetration relationship for stabilized subgrade with (16% CKD)

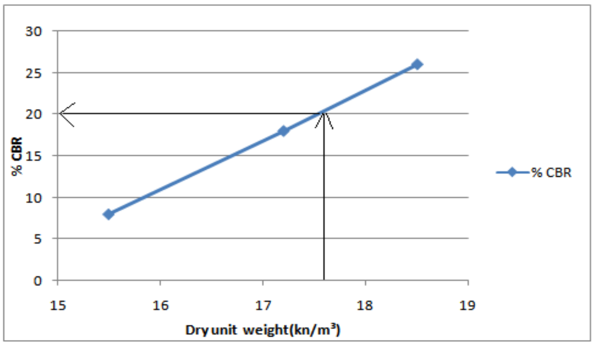

Figure (9) Relationship between CBR and dry unit weight for stabilized subgrade with (16% CKD)

B. Test Results for Base Course Layer

1) Compaction Test

Table (19) summarize the values of Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for base course (aggregate stabilized with 3% cement, aggregate stabilized with 5% cement, recycled concrete aggregate stabilized with 3% cement and recycled concrete aggregate stabilized with 5% cement).

2) Unconfined Compressive Strength Test (UCS)

Two percentages of cement stabilizers are used (3% and 5%) to compare the effect of stabilizer on both types of aggregate used in the construction of base layer; the natural aggregate and recycled concrete aggregate. The two types of aggregate are tested by UCS. The results of UCS test are shown in Table (20) and Figure (10). The results indicate that, the values of UCS test of natural aggregate are higher than that value for recycled concrete aggregate. Also, it can be seen that, increasing the percentage of cement from 3% to 5% significantly increases the UCS values. The increasing is 49.4% for natural aggregate and 41.3% for recycled concrete aggregate.

Table (19) Results of OMC and MDD for base course layer

Base type	Cement stabilizer (%)	OMC (%)	MDD (gm/ cm³)
Natural agg. (AL-Nibaee)	3	6.4	2.18
Natural agg. (AL-Nibaee)	5	7	2.24
Recycled concrete agg.	3	6.8	2.21
Recycled concrete agg.	5	7.6	2.28

Table (20) Unconfined compressive strength (UCS) values

Aggregate type	Cement stabilizer (%)	Average UCS (kPa)
Natural agg. (AL-Nibaee)	3	1135
Natural agg. (AL-Nibaee)	5	1696
Recycled concrete agg.	3	853
Recycled concrete agg.	5	1205

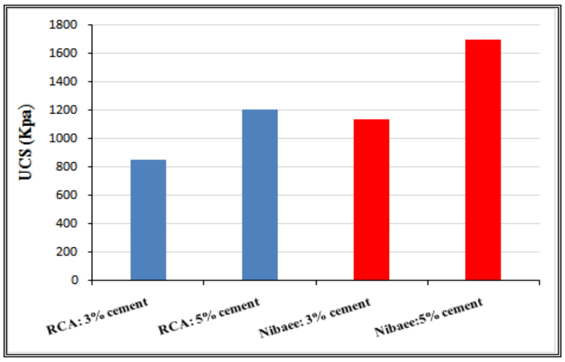

Figure (10) Effect of Cement stabilizer on UCS

C. Test Results of Fresh and Hardened Concrete

As mentioned earlier, the concrete mix which has the highest compressive strength will be adopted (Table (21)). So the concrete mix which contains 20% CKD as an addition of cement weight and PC200 as super plasticizers was adopted in this study to perform the laboratory tests of fresh and hardened concrete samples also to manufacture the different shapes of interlocking concrete blocks.

Table (21) Average compressive strength at ages of 7 and 28 days of all concrete mixes

Type of mix	Age (Day)	Average compressive strength (MPa)				
		0% RCA	25% RCA	50% RCA	75% RCA	100% RCA
Conventional mix	7	18.9	16.4	17.5	15.7	16.1
	28	24.2	22.0	22.7	20.7	20.3
Mix with 20 % CKD	7	22.5	19.6	20.4	18.1	17.1
	28	28.4	25.4	26.2	24.0	22.2
Mix with 20 % CKD & PC200	7	37.5	32.7	33.6	31.4	29.8
	28	47.0	42.1	44.1	40.6	37.5

- The average was taken from three samples of concrete cubes

1) Workability (Slump Test)

As the amount of RCA increase in the mix, the concrete workability decrease because the high water absorption of RCA due to the old mortar presence in the recycled aggregate which required more water to achieve similar workability to that of natural aggregate concrete [33]. In this study the use of super plasticizer improve the concrete mix workability. The slump results of the mixes that contain 20 % CKD as an addition of cement weight and (PC200) as super plasticizers are shown in Table (22).

Table (22) Slump results of tested concrete mix

% RCA in mix	Slump results (mm)
0%	18
25%	16
50%	15.5
75%	11
100%	0.95

2) Density

The average values of density at 7 and 28 days age for concrete cubes (150x150x150mm) are shown in Figure (11). From the results it can be seen that the density of the concrete made from the natural aggregate is decreasing with increasing the percentage of recycled concrete aggregate replacement in the mix. This reduction related to the large amount of old mortar and cement adhering to recycled aggregate which leads to increase air content in the concrete containing recycled aggregate.

3) Compressive strength

Concrete cubes (150 mm x 150 mm x 150 mm) at the age of 7 days and 28 days were tested to find the compression strength for all groups of this study. The results are shown in Table (23) and Figure (12). The average compressive strength of different shapes of interlocking concrete blocks with different percentage of RCA replacement is shown in Table (24).

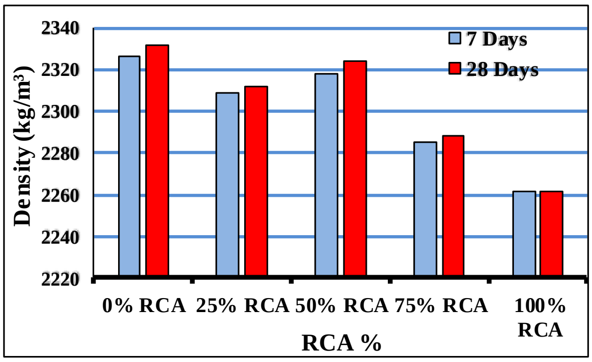

Figure (11) Effect of RCA percentage replacement on concrete density (kg/m³)

In general, it should be noticed that 25% and 50% replacement of natural aggregates by recycled aggregates had little effect on decreasing the compressive strength, especially at 50% but a higher percentage of replacement (75% and 100%) resulted in lower compressive strength for both the concrete cubes and concrete blocks pavers.

Finally it was concluded from that the appropriate percentage of replacement of natural aggregate by recycled concrete aggregate in concrete mixes is 50% which give the highest compressive strength and nearest to the natural aggregate concrete strength. While the 100% percentage replacement of RCA gives the lowest values for the compressive strength.

Table (23) Average compressive strength for concrete cubes with different percentages of RCA replacement at age of 7 and 28 days

Age (Days)	Average compressive strength (MPa)				
	0% RCA	25% RCA	50% RCA	75% RCA	100% RCA
7	37.5	32.7	33.6	31.4	29.8
28	47.0	42.1	44.1	40.6	37.5

- The average was taken from three samples of concrete cubes.

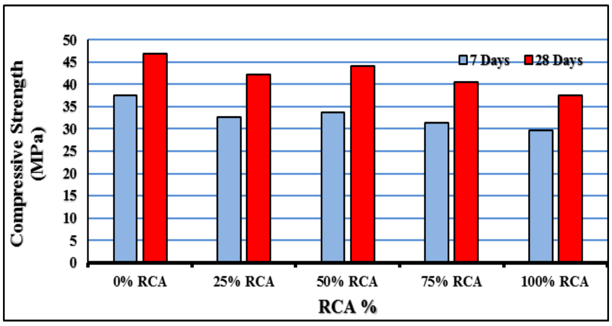

Figure (12) Effect of percentages of RCA replacement on compression strength of concrete cubes at age of 7 and 28 days

Table (24) Average compressive strength for concrete blocks pavers with different percentages of RCA replacement at age of 28 days

Concrete block shape	0% RCA	25% RCA	50% RCA	75% RCA	100% RCA
Rectangular	44.8	42.3	44.0	40.0	38.1
Square	35.7	32.5	33.2	31.3	30.1
L shape	44.4	40.6	41.2	39.2	38.7

- The average was taken from three samples of concrete blocks.

4) Ultrasonic Pulse Velocity Test

This test has proceeded to specify important properties of concrete such as the ultrasonic pulse velocity and the elastic modulus (Es). The elastic modulus (Es) can gain from standard equation using the value of ultrasonic pulse velocity of concrete samples measured by ultrasonic pulse device following ASTM C597-02 [29] specifications, Figure (13) show the average wave velocity for the concrete cubes. Figure (14) show the average wave velocity for the concrete blocks pavers.

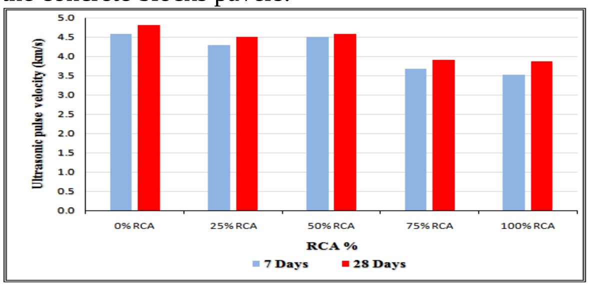

Figure (13) Ultrasonic pulse velocity (km/s) of concrete cubes with different percentages of RCA at age of 7 & 28 days

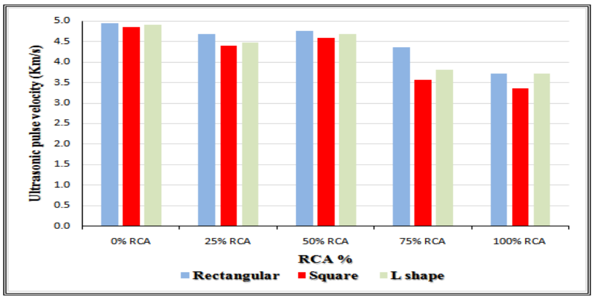

Figure (14) Ultrasonic pulse velocity (km/s) of concrete block pavers with different percentages of RCA at age of 28 days

D. Deflection Test Results

The tests has been carried out on all layers of the pavement which are sub grade, base, and concrete blocks layer with different shapes and laying patterns. A static load has been applied to the surface of concrete pavers to measure the deflection under a specified load.

1) Subgrade Deflection Test Results

A maximum load of 40 kN is applied to the 300 mm thickness of subgrade. The deflection measured using deflection gauge for each 2.5 kN increments of the load from 0 to 40 kN. The accumulative deflection for the subgrade is 1.125 mm at the load of 40 kN. The results of the deflection are shown in Figure (15).

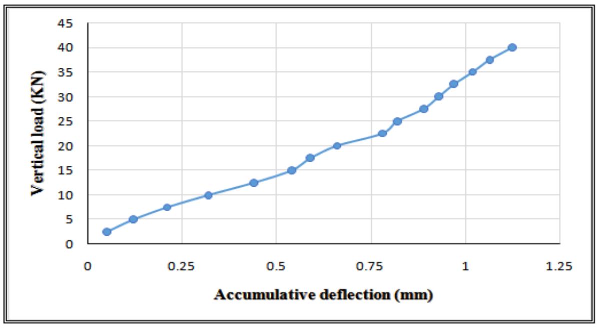

Figure (15) Load-Deflection relationship for subgrade layer

2) Base Course Deflection Test Results

A maximum load of 110 kN is applied to the 685 mm thickness of base course. The deflection is measured using deflection gauge for each 5KN increments of the load from 0 to 110 kN. The accumulative deflection for the subgrade is 3.375 mm at the load of 110 kN. The results of the deflection are shown in Figure (16). The measured deflection will be used later to predict the elastic modulus of base course using back calculation procedure.

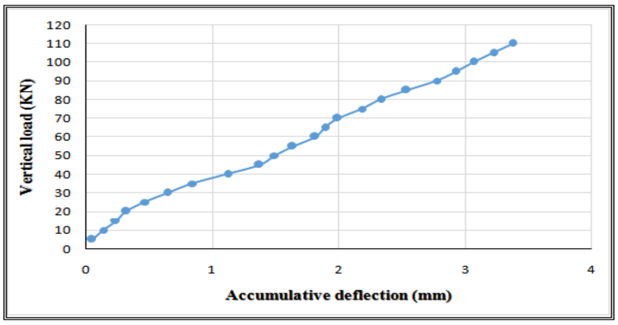

Figure (16) Load-Deflection relationship for base course layer

3) Interlocking Concrete Block Deflection Test

A maximum load of 230 kN is applied to concrete blocks for each shape and laying pattern used in this study. The pavers' deflection is measured using deflection gauge for each 5 kN increments from 0 to 230 kN. The measured deflection will be used later to predict the elastic modulus of concrete blocks using back calculation procedure.

The results of the deflection for each shape and laying pattern of concrete blocks are shown in Figure (17).

Rectangular Concrete Blocks in One Direction Pattern

The accumulative deflection is (6.29 mm) at the load of (230 kN).

Rectangular Concrete Blocks in 45 Degree Herringbone Pattern

The accumulative deflection is (5.66 mm) at the load of (230 kN).

Rectangular Concrete Blocks in Stretcher Bond Pattern

The accumulative deflection is (5.95 mm) at the load of (230 kN).

Square Concrete Blocks

The accumulative deflection is (6.53 mm) at the load of (230 kN).

L shape Concrete Blocks

The accumulative deflection is (6.03 mm) at the load of (230 kN).

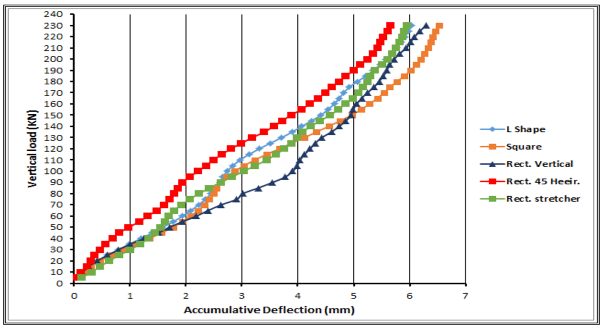

Figure (17) Load-Deflection relationship for concrete blocks

From the results of the measured deflection for all shapes and laying patterns of concrete blocks under investigation, it is concluded that the rectangular concrete blocks are the best shape in comparison with square and L shape concrete blocks and the best laying pattern was the rectangular concrete block with 45 degree herringbone pattern.

IV. PRINCIPLE of BACK CALCULATION

Back calculation is an analytical procedure in which the deflection data used to predict the elastic modulus of different layers of the pavement. The back calculation procedure consists of theoretical calculation of the deflection produced under a known applied load using a supposed set of layer modulus. In this study the back calculation is carried out by using (BAKFAA) software. Table (25) shows that, the results obtained from back calculation using BAKFAA software is less than the modulus obtained from laboratory tests by (20% - 30%). This can be related to the fact that when calculated the modulus for concrete blocks by laboratory tests it is considered as a single layer without any effect of the structure of the pavement (base and subgrade layers), otherwise the modulus obtained from back calculation it is considered more naturalistic because the concrete blocks are in touch with the pavement structure and considered as a surface layer.

Table (25) Comparison between modulus obtained by BAKFAA software and those obtained by laboratory testing

Layer	Modulus (MPa) by laboratory test	Modulus (MPa) by BAKFAA
Subgrade	203	162.4
Base	6391	4601.5
Rectangular concrete block	33380	23366
Square concrete block	28172.2	19720.6
L shape concrete block	31582.9	22108

V. CONCLUSIONS

1. The subgrade layer for aircrafts parking must be stiffened enough to withstand the static load of 230 kN. Therefore, the subgrade soil is treated with 16% CKD as additives to the weight of subgrade. The (CBR) value for the natural subgrade layer is (4.2%), while when adding (16%) CKD to the subgrade, the CBR value is increased up to (20%).
2. When preparing a base layer from non-conventional materials (Recycled Concrete Aggregate (RCA)), the unconfined compressive strength decreases by (25%) in a comparison with a (UCS) for base layer prepared from the conventional materials (Al-Nibaee aggregate). Also, increasing the percentage of cement stabilizer in a base layer from 3% to 5% significantly increases the UCS values. The increasing was 49.4% for Al-Nibaee aggregate and 41.3% for recycled concrete aggregate.
3. Three trail concrete mixes are considered in this study with different percentages of RCA replacement (conventional concrete mix without additives, concrete mix with 20% CKD additives

as an addition to cement weight and concrete mix with 20% CKD additives as an addition to cement weight and (PC200) as super plasticizer. The best mix of concrete to manufacture the concrete blocks pavers and concrete cubes samples is the concrete mix with 20% CKD as an addition to cement weight and (PC200) as super plasticizers, which gives a suitable compressive strength for aircrafts parking up to (37- 47 MPa) with various percentages of RCA replacement.

4. The appropriate replacement percentages of natural aggregate by RCA are (25% and 50%) which slightly decrease the workability of the concrete mix up to (11% and 13.8%) respectively, density of concrete cubes up to (0.86% and 0.34%) respectively and compressive strength of concrete cubes up to (10.4% and 6.2%) respectively as compared with the concrete mixture from natural coarse aggregate for both the concrete cubes and concrete blocks pavers. While with a higher percentages of replacement (75% and 100%) more decreasing effect is noticed on workability up to (38.8% and 94.7%) respectively, density of concrete cubes up to (2% and 3%) respectively and compressive strength of concrete cubes up to (13.6% and 20%) respectively as compared with the concrete mixture from natural coarse aggregate.
5. The laboratory simulation (Box model) test will be carried out on ICBP section to determine the deflection of each layer and use it at back calculation software BAKFAA to determine the layer modulus and to check the ICBP performance. The results were; the subgrade layer can carry load up to (40 kN) with accumulative deflection (1.125 mm), the base layer can carry load up to (110 kN) with accumulative deflection (3.375 mm), and the concrete block layer can carry load up to (230 kN) with accumulative deflection (5.66 mm, 6.53 mm and 6.03 mm) for (rectangular, square and L shape) respectively.
6. By the means of deflection, the best manufactured shape for interlocking concrete block is a rectangular shape (200 mm x100 mm x 80 mm) laying in 45° degree herringbone pattern.
7. The modulus results obtained from back calculation using BAKFAA software is less than the modulus obtained from laboratory tests by (20% - 30%). This can be related to the fact that when calculated the modulus for concrete blocks by laboratory tests it is considered as a single layer without any effect of the structure of the pavement (base and subgrade layers), otherwise the modulus obtained from back calculation it is considered more naturalistic because the concrete block are in touch with the pavement structure and considered as a surface layer.

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