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PROPERTIES OF RECYCLED AGGREGATE IN CONCRETE AND ROAD PAVEMENT APPLICATIONS

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ABSTRACT: This paper highlights the results of the performed testing program which aimed at investigating the possibility of utilizing the recycled crushed aggregates of the construction and demolition wastes (CDW) in engineering applications in Gaza Strip. The characteristics of the crushed aggregates were determined and compared to international standards. The reuse alternative is investigated in concrete mixes and road construction throughout the testing program. Eight representative samples were selected from different locations in Rafah and Khan Younis. A Technical team supervised the collection process, crushing, transporting, handling and testing program. In general, the test results showed that the recycling of the CDW aggregates and its use in both concrete and road sub-base give acceptable results. Most of the characteristic test results were within the standard limits. The results of the tests that concern road applications were good and verified the adequacy of materials. The results of the tests for concrete applications were also desirable and proved that these materials, CDW, could be used in some concrete applications. The values of the CBR ratio at 100% were 186.6 for demolition samples and 186.1 for crushed concrete samples. Comparably with the CBR of the local base course that is ranged between 100 and 130, the CBR values were high due to the large quantity of cementious materials, and achieved the minimum required value (80) for base course at 100% compaction according to AASHTO (T180-D) and (T 193). A local concrete mix design was used for testing CDW use in concrete . This mix gave a compressive strength of about 250 kg/cm2 of compressive strength at 28 days at water to cement ratio of 0.6 and 290 kg cement content. The results of the testing program of the recycled CDW were above expectations and showed, to some extent, good indications. Two testing labs were used to prepare and test the samples. Most tests at 7 and 28 days, showed high results compared to the control samples of natural materials. The results of the compressive strength of all samples at the same water to cement ratio were close to each other.

KEYWORDS: Construction and Demolition Wastes, Recycling, Concrete Mixes, Road Applications.

خصائص الحصويات المعادة التصنيع في تطبيقات صناعة الخرسانة ورصف الطرق

رفعت رستم، صلاح طه، علي بدارنة، هاني البراهمة

الخلاصة: ورقة العمل هذه تلقي الضوء على نتائج برنامج الفحوصات الذي تم إجراؤه والذي هدف إلى توضيح إمكانية إنتاج حصويات مسحوقة (معاد تصنيعها) من مخلفات البناء والهدم. وبينت ورقة العمل خصائص الحصويات المسحوقة وقارنتها بالمعايير الدولية. وقد تم فحص خيار إعادة الاستخدام كبديل في الخلطات الخرسانية وإنشاء الطرق خلال برنامج الفحوصات. وتم انتقاء ثماني عينات ممثلة من مواقع مختلفة في رفح وخانيونس. وأشرف على عملية جمع العينات وسحقها ونقلها والتعامل معها وكذلك برنامج الفحوصات فريق مهني. وبصورة عامة، فقد أثبتت الفحوصات أن الحصويات المعاد تصنيعها واستخدامها في صناعة الخرسانة وطبقة الأساس في الطرق تعطي نتائج مقبولة. وكانت معظم نتائج فحص خصائص الحصويات ضمن الحدود المقبولة. وكانت نتائج الفحوصات المتعلقة بالتطبيقات في الطرق جيدة وتؤكد ملاءمة المواد. ونتائج الفحوصات في التطبيقات الخرسانية كانت أيضا مرضية وتثبت أن هذه المواد يمكن استخدامها في بعض التطبيقات الخرسانية. أما نتائج اختبار معامل تحمل كاليفورنيا (CBR) عند درجة دمك 100% فكانت 186.6 لعينة الركام و 186.1 لعينة الخرسانة المسحوقة. ومقارنة بقيمة معامل تحمل كاليفورنيا للمواد المحلية المستخدمة في طبقة الأساس والتي تتراوح بين 100 و 130 كانت القيم مرتفعة نتيجة للكمية الكبيرة من المواد الإسمنتية، وحققت الحد الأدنى المطلوب (80) لطبقة الأساس عند درجة دمك 100% طبقا لمواصفات الآشتو AASHTO - (T180-D) و (T 193). وقد تم تصميم خلطة خرسانية محلية لاستخدامها في فحص استخدام مخلفات البناء والهدم في مجال الخرسانة. هذه الخلطة تعطي (حسب التصميم) 250 كجم/سم^2 كقوة تحمل عند 28 يوم بمعدل 0.6 ماء إلى اسمنت و 290 كجم محتوى إسمنتي. نتائج الفحوصات للمخلفات المعاد تصنيعها كانت أعلى من التوقعات وأعطت مؤشرات ايجابية إلى حد ما. وقد تم تحضير العينات للفحص من خلال مختبرين محليين لفحص المواد. ومعظم الفحوصات التي أجريت عند 7 أيام و 28 يوم أظهرت قيما مرتفعة مقارنة بعينات المقارنة المرجعية المصنعة من المواد الطبيعية. وكانت نتائج فحص قوة التحمل لجميع العينات عند ذات معدل الماء إلى الاسمنت متقاربة مع بعضها.

INTRODUCTION

The recycling of Construction and Demolition Wastes (CDW) has long been recognized to have the potential to conserve natural resources and to reduce energy used in production. In some countries it is a standard alternative for both construction and maintenance, particularly where there is a shortage of construction aggregate.

The objective of this paper is to determine the technical feasibility/applicability of using the recycled CDW in Gaza Strip in concrete mixes and road construction as an alternative for natural aggregate. A detailed testing program was conducted. The findings of this paper will assist in drawing a clear picture about the applications of crushed CDW in Gaza Strip. The results will also provide a technical recommendation to the regulatory agencies to issue the standards and technical specifications for the materials of concern.

BACKGROUND

Gaza Strip is a small closed coastal area (365 Km^2) and a densely populated area with population of 1,443,814 according to the mid of year 2006 statistics[i]. The disposal of CDW in Gaza Strip is one of the challenging problems; due to the scarcity of open lands and the limited size of municipal dumping sites to accommodate large quantities of debris and unprocessed construction wastes. The random and uncontrolled disposal of CDW create several environmental impacts.

A survey by the Islamic University of Gaza in 2002 indicated that more than 1 million m^3 of CDW are distributed over 21 main sites in Gaza Strip[ii]. The most recent assessment of the CDW quantities in Rafah and Khan Younis are estimated at about 0.25 million m3 [iii].

Some local temporary activities were used to minimize the problem of CDW; upgrading low level areas, construction of rural and county roads, emergency - fisherman harbor, cover materials in solid waste landfills, and reuse in manufacturing of concrete hollow block (pilot projects). It is worth to mention here that, before this investigation, there is no comprehensive testing program was performed to test the applicability of CDW in engineering applications, only limited tests and investigations were performed by students in local universities.

LITERATURE OF CDW CHARACTERISTICS AND APPLICATIONS

A study was prepared by Lohja Rudus Environmental Technology Ltd[iv] showed that the crushed concrete materials has a 2-3 times better bearing capacity than gravel or crushed rock allowing the reduction of the road base thickness. The studies showed that the E-modulus of crushed concrete is 2-5 times higher than the natural materials. Its water demand is higher (8-10% optimum water content and 1950 kg/m3 maximum dry density). The crushing costs were higher than costs of crushing natural materials. In Russia[v], the recycled aggregates have been used for foundation purposes and for production of new structural concrete up to a characteristic strength of 20 MPa and it is also used as mineral filler in asphalt. In the UK, Thomas Telford[vi] has investigated the alternative materials in road construction. Telford described the physical and chemical properties of the alternative materials 'wastes and by-products' and concludes that these materials have some potential for use in road construction.

Locally, several limited research were conducted to investigate the applicability of recycled CDW in engineering applications, three fields covered were; concrete mixes, roads construction and hollow block production. The main findings were[2,vii]:

- Concrete made with recycled CDW has a compressive strength (28days) about 27% - 30% less than the strength of the concrete made with natural aggregates
- The was carried out for soaked samples. No swelling is noticed in any CBR test. The results of physical tests indicate the applicability of crushed materials in road constructions
- Concrete Hollow Blocks made with recycled aggregate has compressive strength about (12 – 21)% less than that of CHB made with natural aggregate. And for the same compressive strength the cost of with recycled aggregate is less than the cost of those with natural aggregate.

DESIGN OF THE TESTING PROGRAM

A comprehensive testing program was designed to determine the applicability of utilizing local CDW in engineering applications[viii]. The testing program investigated initially the physical characteristics of CDW materials. The characteristics tests were followed by two sets of tests; concrete mixes tests and road construction tests. Two labs were selected to perform the tests; Islamic University of Gaza Lab (IUG) and Association of Engineers Lab (AE). Technically, the samples were classified into pure demolished concrete samples and mix demolished samples. The investigated sites and samples are outlined in Table 1.

Table 1: Investigated sites and samples

Location		Location Name	Label of Pure Concrete Sample	Label of Mixed Demolition Sample
Rafah (R)	Site 1	Al Barazil	R1C	R1D
	Site 2	Block J		R2D
	Site 3	Road No. 4	R2C	
Khan Younis (K)	Site 1	Al Amal	K1C	K1D
	Site 2	The Cemetery	K2C	K2D

The samples were classified and labeled according to their sources, location and type. Sieving to remove impurities and large pieces as well as a general description of shape and texture was performed. Concrete mixes were prepared using pure demolished concrete samples only while the tests for road applications were conducted using the two types. The required tests and their standards for the CDW samples are listed in Table 2.

Table 2: Characteristic and Application Tests for the CDW samples

Test	Number of Tests	Standard
Materials Characteristics Tests		
§ Sieve Analysis	8	ASTM D – 422
§ Liquid Limit, Plastic Limit and Plasticity Index	8	ASTM D – 4318
§ Specific Gravity and Absorption	8	ASTM D – 854
§ Water Content	8	ASTM D – 2216
§ Flakiness and Elongation	8	BS 812
§ Clay lumps and Friable particles	8	ASTM C – 142
§ Light weight pieces	8	ASTM C – 123
§ Finer than #200 sieve by washing	8	ASTM D – 1140
Tests for Applications in Road Construction		
§ Compaction Test	8	ASTM D – 1557
§ Los Angeles Abrasion Test	8	ASTM C – 131
§ CBR (California bearing Ratio)	8	ASTM D – 1883
§ Sand Equivalent value	8	ASTM D – 2149
§ Impact Test	8	BS 812
§ Crushing Value test	8	BS 812
Tests for Applications in Concrete Mixes		
§ Slump Test (one per mix)	12	ASTM C – 143
§ Air Content (one per mix)	12	ASTM C 231
§ Compressive Strength, 12 mixes (six cubes per mix, three at 7 days and three at 28 days).	72 cubes	BS 1881

The following sections highlight the results of the performed characteristic tests, concrete mixes tests and road construction tests. It is worth to mention that for all performed tests, there is no significant difference between the results of the two testing labs (IUG and AE).

ANALYSIS OF CHARACTERISTIC TESTS

Sieve Analysis

The sieve analysis, gradation test, shows the distribution of aggregate particles, by size, within a given sample in order to determine compliance with design, production control requirements, and verification of specifications. The collected samples of crushed CDW were sieved and the results were plotted on a logarithmic scale to compare with the standard values of AASHTO for base course materials grade (A). Moreover, the gradation test shows that the samples are going down to lower standard limit which represents the course limit. Some of the samples were courser than the standard limits and others were slightly matching these limits. From a technical point of view, this gradation is acceptable to some extent. However, as will be discussed in the following sections, the other tests such as impact test and Los Angeles Abrasion test are of high values, outside the standard limits, which indicate that the aggregate would become smaller during the compaction process in the field.

Moreover, the results reveal that the samples are classified as coarse samples if used in concrete applications according to ASTM; hence the greatest constituent of the samples is course, greater than 4.75 mm (sieve no. 4). The course and fine materials in the demolition samples were, on average, 73.1 and 26.9% respectively. Likewise for crushed concrete samples, the course and fine materials were on average 84 and 16%, respectively. The difference between the results of the two labs (IUG and AE) were insignificant. The results of sieve analysis of the collected samples in comparison with ASTM standard limits for concrete applications indicate that the aggregate of size greater than 2.5 cm was representing the major portion in the tested materials. If this considerable portion is separated from the samples by using sieves at the crushing site, the results then could be consistent with the ASTM standards.

The subsequent scenarios for road applications could be to use the material as it is (in sub-base layers and side walks) and to use the material after mixing with natural materials (crushed rock stones) with an amount of 20-30% in order to improve some characteristics. However, the mixing option needs further investigation. On the other hand, the subsequent scenarios for concrete applications could be to use only the particle sizes of less than 2.5 cm. The removed particles (greater than 2.5 cm) could be mixed again for road applications or re-crushed to produce smaller particles. Accordingly, it is recommended to use sieves at the crushing site. The sieved particles are preferred to be classified according to the prevailing local market sizes and local common names which are: Folia (25-4.75mm), Adasia (12.5-4.75mm), and Semsemia (9.5-2.36mm).

Atterberg limits

The results of Atterberg limits (liquid limit and plastic limit) show that the average values of liquid limit for demolition and crushed concrete samples were respectively 22.1% and 24.7%, which are in compliance with AASHTO and ASTM requirements for sub-base and base materials (not greater than 25%) according to AASHTO (M147-65, 1980) and ASTM (D2940-74, 1985). The crushed concrete samples have values greater than the demolition ones. This could be justified by the high percent of cementious materials in the crushed concrete samples since the demolition samples contain some sand which work in minimizing the liquid limit value. Moreover, both demolition and crushed concrete samples are non-plastic, which indicate their good performance in road applications. The plasticity index is a relationship between plastic limit and liquid limit, so it is not applicable because of the absence of plastic values.

Specific Gravity, Water Content and Absorption

The specific gravity of natural materials is in the range of 2.570-2.685. The specific gravity of the tested CDW samples ranged between 2.35 and 2.44 (2.4 in average), which is lower than crushed natural rock stone. It is noticed that the natural aggregate has higher specific gravity due to the soundness of the natural rock stone and the lower porosity.

The water content is in the normal range at stock pile condition. However, this value could change based on the weather conditions and season. The water content of the demolition waste was on average 1.2% and 1.7% for concrete crushed samples.

The Absorption values were 5.9% for demolition samples and 6% for concrete samples. The results of the absorption test reveal that the samples have higher absorption value, greater than 5% in general for both, compared to natural materials which have maximum absorption values of 2.2-3.8%. It is observed that the demolition samples have absorption values higher than crushed concrete samples. This is expected, because the demolition samples include more impurities; plasters, tiles, blocks, etc. which increase the absorption capacity. Therefore, it is recommended to study the behavior of concrete mixes (with crushed CDW) for durability. The high values of absorption could produce permeable concrete and susceptibility to weather conditions and liquids. The amount of water that an aggregate can absorb tends to be an excellent indicator as to the strength of the aggregate, or should say weakness. Strong aggregates will have a very low absorption figure, i.e. below 1%. Above 4% absorption further tests should be performed to determine the aggregates acceptability, it may be frost susceptible. An aggregate with high moisture absorption is not likely to be an acceptable road building material, e.g. soft limestones. In our tested materials, the absorption percentage that accounts for 6%, on average, is considered to be quit acceptable under the environmental conditions of Palestine.

Finer than #200 sieve by washing

The percentage of finer than #200 sieve by washing for demolition waste was on average 3.5% and 1.8% for concrete crushed samples. High percent of finer than sieve #200 is observed in the demolition samples, since the later contain some silt and clay materials. High percent of finer than # 200 materials lead to increase the absorption capacity (large surface area) and to reduce the workability of concrete mixes.

Clay lumps and friable particles

This test method is of primary significance in determining the acceptability (quality) of aggregate with respect to the requirements of specification. Excessive clay lumps in a processed aggregate intended for concrete and road construction may interfere with the bonding between the aggregate and cementitious material. This will result in raveling or stripping and creating weak points and pop-outs if the material is incorporated into the pavement or structure. Aggregate intended to perform as a drainable base or sub-base may also be adversely affected when excess amounts of clay and friable particles are present. This type of material tends to fill the void spaces intended for drainability, eventually contributing to pavement failure. The percent finer than sieve #200 were 2.8% and 1.8% for demolition samples and concrete samples respectively. Accordingly, the percentages of clay lumps and friable particles obtained in the tested samples are small, which is acceptable for construction applications.

Flakiness and Elongation

The flakiness index for the tested demolition and crushed concrete samples are, on average, 16.9 and 10.8 respectively. The results are consistent with the BS 882: 1992; since the later requires the flakiness index of the crushed rock or crushed gravel intended to be used in road construction, less than 40. Moreover, the flakiness index and elongation index values for crushed concrete samples are less than those obtained from demolition samples which can be attributed to the presence of blocks, plaster and other soft materials. The elongation index for the tested demolition and crushed concrete samples are, on average, 20.7 and 15 respectively. The results are consistent with the BS 882: 1992; since the later requires the elongation index of the crushed rock or crushed gravel intended to be used in road construction to be less than 40.

Road Tests

Compaction Test

The main objective of the compaction test is to determine the maximum dry density and the corresponding Optimum Moisture Content (OMC). As presented in Table 3, the results at the optimum water content reveal that the average maximum dry density for demolition and crushed concrete samples equals to 2.0 g/cm^3. Likewise, the average optimum water content was 9.74 and 10.7 respectively for demolition and crushed concrete samples.

Table 3: Optimum Water Content (OWC) and Maximum Dry Density (MDD) in the Tested CDW Samples

Sample	**Islamic University Lab**		**Association of Engineers Lab**		**Sample**	**Islamic University Lab**		**Association of Engineers Lab**	
	OWC	**MDD**	**OWC**	**MDD**		**OWC**	**MDD**	**OWC**	**MDD**
R1D	12.10	2.03	10.60	1.97	R1C	12.2	2.025	8.4	1.976
R2D	9.30	1.99	8.80	2.00	R2C	12.4	1.95	11.2	1.978
K1D	10.50	1.98	9.10	1.98	K1C	14.4	1.97	8.2	2.066
K2D	9.70	2.03	7.80	2.02	K2C	10	1.97	9.1	2.067
Average	**10.40**	**2.01**	**9.08**	**1.99**	Average	**12.3**	**2.0**	**9.2**	**2.0**
	Average of two labs for OWC = 9.74 and 2.0 for MDD					Average of two labs for OWC = 10.7 and 2.0 for MDD			

Los Angeles Abrasion Test

The Los Angeles test is a measure of mineral aggregate gradation of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres (ASTM C 131-89). The test was carried out to compare between the Los Angeles values of CDW and AASHTO maximum allowed value, to be used in the road construction as base course material, which is 45% at 500 revolutions. The results of Los Angeles abrasion test is presented in Table 4 at different revolutions. The values of Los Angeles Abrasion Tests do not show substantially high values. The average Los Angeles values for the demolition and crushed concrete samples at 500 revolutions were 48.8% and 41.5% respectively, which indicate that the crushed concrete wastes are more adequate to be used as a base course in road applications rather than demolition wastes, based on AASHTO T 96. However, 48.8% can be considered tolerable compared to 45% for road applications. Moreover, the ratio of wear loss (abrasion after 100 Rev. /abrasion after 500 Rev) was 36.7 and 28.91 respectively for demolition and crushed concrete samples. These ratios are not in compliance with AASHTO standard since the ratio of wear loss should not be more than 20% of the maximum allowed abrasion after 500 Rev, for base course in roads structures.

<u>California Bearing Ratio Test "CBR"</u>

California Bearing Ratio Test (CBR) is used to measure the bearing strength of a soil under standard conditions. The stronger the subgrade (the higher the CBR reading) the less thick it is necessary to design and construct the road pavement, this gives a considerable cost saving. Conversely if CBR testing indicates the subgrade is weak (a low CBR reading) a suitable thicker road pavement should be constructed to spread the wheel load over a greater area of the weak subgrade in order that the weak subgrade material is not deformed, causing the road pavement to fail. The CBR values for the tested CDW samples are presented in Table 5. As shown, the values of the CBR ratio at 100% were 186.6 for demolition samples and 186.1 for crushed concrete samples. Comparably with the local base course that is ranged between 100 and 130, the CBR values were high due to the large quantity of cementious materials, and achieved the minimum required value (80) for base course at 100% compaction according to AASHTO (T180-D) and T 193. The results verify the adequacy of using recycled aggregate in road construction with respect to CBR values.

<u>Sand Equivalent Value, Impact Test and Crushing Value Test</u>

Sand equivalent (ASTM D 2419-95) may be defined as a measure of the amount of silt or clay contamination in the fine aggregate. The results of sand equivalent tests are presented in Table 6. The sand equivalent value was on average around 64% for demolition samples and was on average around 81% for crushed concrete samples. These values are in compliance with the local standards for base course, which revealed that the base course material should contain a minimum of 35% sand equivalent at any stage of road construction.

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Table 4: Percentages of Los Angeles Test Values in the Tested CDW Samples at 100 and 500 Revolutions.

Sample	**Islamic University Lab**		**Association of Engineers Lab**		**Sample**	**Islamic University Lab**		**Association of Engineers Lab**	
	LA@100 Rev.	**LA@500 Rev.**	**LA@100 Rev.**	**LA@500 Rev.**		**LA@100 Rev.**	**LA@500 Rev.**	**LA@100 Rev.**	**LA@500 Rev.**
R1D	12	41	12.6	43.7	R1C	13	41	12	43.6
R2D	16	45.3	18.2	36.1	R2C	10.4	38.2	15.4	44.6
K1D	20	55	18.7	56.5	K1C	10.6	40	11	42.3
K2D	22	55	23.7	58	K2C	11	39.4	12.7	43.2
Average	**17.5**	**49.1**	**18.3**	**48.6**	Average	**11.3**	**39.7**	**12.8**	**43.4**
	Average of two labs = 17.9% @ 100 Rev. and 48.8% @ 500 Rev.					Average of two labs = 12% @ 100 Rev. and 41.5% @ 500 Rev.			

Table 5: CBR Values in the Tested CDW Samples at 95, 98 and 100% Compaction

Sample	**Islamic University Lab**			**Association of Engineers Lab**			**Sample**	**Islamic University Lab**			**Association of Engineers Lab**		
	CBR @ 95%	**CBR @ 98%**	**CBR @ 100%**	**CBR @ 95%**	**CBR @ 98%**	**CBR @ 100%**		**CBR @ 95%**	**CBR @ 98%**	**CBR @ 100%**	**CBR @ 95%**	**CBR @ 98%**	**CBR @ 100%**
R1D	87	156	220	71	126	187	R1C	100	170	222	87	117	128
R2D	113	150	198	85	130	172	R2C	111	177	226	83	133	162
K1D	116	168	204	10	99	123	K1C	53	150	204	68	121	169
K2D	102	172	225	84	129	164	K2C	155	209	223	82	122	155
Average	**104.5**	**161.5**	**211.75**	**62.5**	**121**	**161.5**	Average	**104.75**	**176.5**	**218.75**	**80**	**123.25**	**153.5**
	Average of two labs @ 95% = 83.5, @98% = 141.3 and @100% = 186.6							Average of two labs @ 95% = 92.3, @98% = 149.9 and @100% = 186.1					

Table 6: Sand Equivalent Value, Impact Value and Crushing Value Tests

Sample	Islamic University Lab			Association of Engineers Lab			Sample	Islamic University Lab			Association of Engineers Lab		
	SEV*	**IV***	**CV***	**SEV**	**IV**	**CV**		**SEV**	**IV**	**CV**	**SEV**	**IV**	**CV**
R1D	81.1	24.4	41	49	30	28.7	R1C	75	24	30	86	23	27.9
R2D	80	33.7	32.6	66	30	38.7	R2C	83	25.3	27	90	27	26.7
K1D	63	36	33.7	46	34	37.9	K1C	88	28	24.7	88	26	31.9
K2D	62.5	39	34	61	33	37	K2C	72.5	26	21	67	24	30.2
Average	**71.7**	**33.3**	**35.3**	**55.5**	**31.8**	**35.6**	Average	**79.6**	**25.8**	**25.7**	**82.8**	**25**	**29.2**

* SEV; Sand Equivalent Value, IV; Impact Test, CV; Crushing Value

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Aggregate Impact Values “Toughness” and Aggregate Crushing Values are often numerically very similar, and indicate similar aggregate strength properties. Aggregate Impact Values, (AIV's), below 10 are regarded as strong, and AIV's above 35 would normally be regarded as too weak for use in road surfaces. BS 882: 1992 prescribes the following maximum values of the average of duplicate samples:

- 25% when the aggregate is to be used in heavy-duty concrete floor finishes.
- 30% when the aggregate is to be used in concrete pavement wearing surfaces,
- 45% when to be used in other concrete applications.

The average values of impact test were 33.2 for demolition samples, and 25.8 for crushed concrete samples, which indicate that the tested samples are suitable for the above mentioned applications according to BS 882.

The aggregate crushing value test is a useful guide when dealing with aggregates of unknown performance. The aggregate crushing value provides a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load.

The aggregate crushing value is a value which indicates the ability of an aggregate to resist crushing. There is no explicit relation between the aggregate crushing value and its compressive strength but, in general, the crushing value is greater for a lower compressive strength. For crushing values of over 25 to 30, the test is rather insensitive to the variation in strength of weaker aggregates.

CONCRETE TESTS

Mix Design

For concrete tests, the mix was designed based on the physical properties obtained at three different water/cement ratios. The labs coordinated with the Ministry of Public Works and Housing regarding the mix design (their standard mix design was adopted). The labs prepared the concrete samples (mixing, placing, and curing). Mixing was done using 0.20 m^3 rotating drum mixer. Standard procedures were followed in concrete mixing and specimens preparation (cubes).

The Specific Gravity of Course Aggregate (SG_{SSD}) is 2.4, the Specific Gravity of Fine Aggregate for crushed concrete (SG_{dry}) is 2.4, and the Specific Gravity of Fine aggregate for natural sand (SG_{dry}) is 2.65. Table 8 summaries the results of concrete tests at different water cement ratios.

Table 7: Mix proportions used in the testing program of concrete

Material	Quantity of Materials by Weight		
W/C (water to Cement Ratio)	0.65	0.58	0.5
Cement Content (Kg/m³)	290	290	290
Water			
- water necessary for the mix (L)	188	168	145
- water quantity for absorption (L)	12	12	15
Total Quantity of Water (L)	200	180	160
Course Aggregate (less than 1") (Kg/m³)	1,100	1,135	1,170
Fine Aggregate (crushed concrete) (Kg/m³)	300	308	315
Fine aggregate (Natural Sand) (Kg/m³)	330	340	350
Admixture (L)	2	2	2

Results of Fresh Concrete Tests

Slump Test (one per mix)

The slump test is the oldest and most widely used to measure the workability of fresh concrete. It is used to determine the slump of concrete, both in laboratory and in field according to (ASTM C143-90a). The average slump values were 197.5, 140.6 and 58.8 mm at 0.65, 0.58 and 0.50 water to cement ratio respectively. This indicates a good performance and workable concrete mixes. The use of admixtures (MRL 100) helped in this regard. Using of natural aggregate at the same conditions is expected to give a higher slump value. This can be attributed to the fact that crushed concrete aggregate have higher angularity and surface to volume ratio than other types of aggregate, which means higher mechanical work is needed to overcome the resulting internal friction and higher mixing water is therefore needed.

Air Content (one per mix)

The pressure method, Type B pressure meter and ASTM C231-91a, was used to measure the air content. Table 8 shows the values of the air content. The air content ranges from 1.8 to 3.5%. These values are within the acceptable range. The air content of concrete made with natural aggregate ranges between 1 and 2%. Values of more than 6% request some measures especially concerning concrete durability.

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Table 8: Summary of the results of concrete tests at different water cement ratios

W/C Ratio	Islamic University Lab					Association of Engineers Lab				
	R1C	R2C	K1C	K2C	average	R1C	R2C	K1C	K2C	average
	Compressive Strength (kg/cm^2) - 28 days					Compressive Strength (kg/cm^2) - 28 days				
0.65	254.5	252.9	252.6	239.4	249.9	300.0	278.0	260.0	264.0	275.5
0.58	313.7	301.2	290.6	313.6	304.8	316.0	335.0	296.0	311.0	314.5
0.50	370.3	353.1	368.0	345.4	359.2	387.0	365.0	320.0	383.0	363.8
W/C Ratio	Compressive Strength (kg/cm^2) - 7 days					Compressive Strength (kg/cm^2) - 7 days				
	R1C	R2C	K1C	K2C	average	R1C	R2C	K1C	K2C	average
0.65	185.5	183.9	170.3	162.9	175.7	200.0	166.0	177.0	168.0	177.8
0.58	240.3	236.6	213.1	232.0	230.5	240.0	220.0	188.0	203.0	212.8
0.50	260.4	263.7	254.2	256.5	258.7	285.0	251.0	256.0	261.0	263.3
W/C Ratio	Slump (5 min) (mm)					Slump (5 min) (mm)				
	R1C	R2C	K1C	K2C	Average	R1C	R2C	K1C	K2C	Average
0.65	170.0	205.0	200.0	210.0	196.3	160.0	210.0	215.0	210.0	198.8
0.58	155.0	130.0	180.0	90.0	138.8	125.0	140.0	160.0	145.0	142.5
0.50	90.0	50.0	50.0	50.0	60.0	45.0	70.0	50.0	65.0	57.5

PROPERTIES OF RECYCLED AGGREGATE IN CONCRETE

W/C Ratio	Air Content (%)					Air Content (%)				
	R1C	R2C	K1C	K2C	Average	R1C	R2C	K1C	K2C	Average
0.65	2.5	3.5	2.5	3.5	3.0	1.9	1.8	1.8	1.9	1.9
0.58	3.3	3.5	3.5	3.0	3.3	2.2	2.0	2.1	2.0	2.1
0.50	3.0	3.0	3.0	3.5	3.1	3.6	3.0	3.5	3.0	3.3

W/C Ratio	Density (kg/m^3)					Density (kg/m^3)				
	R1C	R2C	K1C	K2C	Average	R1C	R2C	K1C	K2C	Average
0.65	2255.0	2246.0	2259.0	2226.0	2246.5	2238.0	2224.0	2254.0	2241.0	2239.3
0.58	2257.0	2253.0	2253.0	2229.0	2248.0	2192.0	2237.0	2258.0	2273.0	2240.0
0.50	2268.0	2268.0	2276.0	2253.0	2266.3	2276.0	2225.0	2280.0	2238.0	2254.8

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Results of Hardened Concrete Tests

Density

The average unit weight of concrete was 2250 kg/m^3 for all samples, where the unit weight of local concrete is about 2400 kg/m^3. This could be justified as the unit weight of the recycled aggregate itself is smaller than the natural crushed aggregate. The BSG of crushed aggregate is about 90-92% of those for natural aggregate. Also the percent of air content measured in control mixes is lower than the mix produced using recycled aggregate.

Compressive Strength

A local mix design was used (Ministry of Public Works and Housing B250 Nominal Mix). This mix gives about 250 kg/cm^2 compressive strength at 28 days at water to cement ratio of 0.6 and 290kg cement content. The results of the testing program were above expectations and showed, to some extent, good indications. All values of 28 days tests were above the control value, 250 kg/cm^2. Most tests at 7 days and 28 days, showed high results compared to the control samples of natural materials. However, the results could be justified as the samples, crushed materials, were selective and free of impurities as well as the materials were handled, mixed and tested under high conditions of control. The ratio of 7 days to 28 days compressive strength of concrete ranges from 60% to 80% ,which is within the normal ranges. In general, the following observations could be reported:

§ The results of compressive strength of all samples at the same water to cement ratio are close to each other. The difference is marginally negligible (i.e. 6% for Islamic University Laboratory results and 14% for Association of Engineers Laboratory results).

§ The lower the water cement ratio the higher compressive strength for all samples, but with lower workability.

§ Sample R1C which is collected from Rafah (Al Barazil Area) gives the highest value of strength under all conditions. This result meets the expectations of the professionals during samples collection. It is crushed from newly demolished concrete elements.

In practice, and if the waste material is to be used in concrete applications, reduction factor should be considered to account for the variability and heterogeneity of CDW as well as impurities included. A 20% to 30% reduction factor is proposed.

CONCLUSIONS AND RECOMMENDATIONS

The test results showed that the recycling of the CDW aggregates and its use in both concrete and road sub-base gives acceptable results. Thus, recycled aggregates can be considered as a good alternative to natural aggregates especially in road construction. Most of the characteristic test results were within the standard limits. The results of the tests that concern road applications were very good and verified the adequacy of materials. The results of the tests for concrete applications were also desirable and proved that these materials, CDW, could be used in some concrete applications. However, in order to clearly outline the specifications required for road and concrete applications, more investigations are required to observe the field performance of these materials and their durability.

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