

Evaluation of Using the Crushed Concrete Aggregate as Unbound Pavement Layer

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Abstract

Population increase and economic developments can lead to construction as well as demolition of infrastructures such as buildings, bridges, roads, etc and the used concrete is the main waste product of them. Recycling of waste concrete to obtain the recycled concrete aggregates (RCA) for base and/or sub-base materials in road construction is a foremost application to be promoted to gain economical and sustainable benefits. Recycled Concrete Aggregate was taken from the tested samples of concrete cubes in the consultant bureau. The samples belong to the same group in order to ensure that they have the same composition. This aggregate was used to produce three groups of samples: graded as subbase (type B) and base course according to Iraqi specifications for roads and bridges. Two groups graded as subbase but with difference in amount of materials passing sieve size 0.075 mm (0%, 5%). The other sample was graded as base course with (5%) the lowest limit of materials passing sieve size (0.075) mm. The experimental tests adopted are: Atterberg limits, Moisture-density relationship, and California Bearing Ratio.

CBR test's results obtained from the Recycled Concrete Aggregate are still showing the highest values as compared with the ordinary local subbase materials, they show an increment by 28% when the RCA without filler and 80% when the RCA with 5% filler, the values are also high for base course exceeds the requirements by 60% increment. In light of the Iraqi specifications for roads and bridges they can be used as base and/or subbase course layer. To increase the CBR value the RCA needs the lowest amount of materials that pass the sieve size (0.075) mm.

Key words: Crushed Concrete Aggregate, Recycled Concrete Aggregates (RCA), California Bearing Ratio (CBR), unbound base and subbase course.

الخلاصة

الزيادة السكانية والتطورات الاقتصادية يمكن أن تقود إلى البناء، فضلا عن هدم البنى التحتية مثل المباني والجسور والطرق، وغيرها، و الخرسانة المستعملة هي نتاج الرئيسي منها. اعادة تدوير النفايات الخرسانية الغرض الرئيسي للحصول على RCA واستعماله كطبقة اساس او تحت الاساس في انشاء الطرق لغرض المكاسب الاقتصادية والبيئية وعملية البناء المستدام. اخذ ركام الخرسانة المدور من نماذج مكعبات مفحوصه من مكتب استشاري وهي من نفس المجموعه لغرض التأكد انها من نفس التركيب، هذا الركام استعمل لانتاج ثلاث مجاميع من النماذج: درجت كندرج طبقه تحت اساس صنف (B) و كندرج طبقه اساس طبقا للمواصفات العراقية للطرق والجسور. مجموعتين درجت كندرج طبقه تحت الاساس لكن مع اختلاف في كمية المواد العابره من منخل حجم (0.075) ملم (0% و 5%). مجموعة درجت كندرج طبقه الاساس مع (5%) كحد ادنى من المواد العابره من منخل حجم (0.075) ملم. الفحوصات المختبريه التي اعتمدت هي: حدود (Atterberg)، علاقة الكثافه بالرطوبه ونسبة التحمل الكاليفورني. النتائج المستحصله من فحص نسبة التحمل الكاليفورني لركام الخرسانه المدور لازالت تظهر قيم عاليه مقارنة مع مواد تحت الاساس الاعتيادي المحليه، الزيادة كانت 28% مع النماذج بدون مواد مائه و 80% للنماذج ذات 5% مواد مائه، كذلك عاليه مقارنة مع متطلبات طبقه الاساس بزياده 60% وانها توافق المواصفات العراقيه للطرق والجسور للاستعمال كطبقة اساس وتحت الاساس. لزيادة قيمة نسبة التحمل الكاليفورني فان ركام الخرسانه المدور يحتاج لادنى حد من المواد العابره من منخل (0,075) ملم.

الكلمات المفتاحية: ركام الخرسانه المكسره، ركام الخرسانه المدور، نسبة التحمل الكاليفورني، طبقه الاساس الغير مترابط وطبقة تحت الاساس الغير مترابط.

1-Introduction and Literature Review:

Population increase and economic developments can lead to construction as well as demolition of infrastructures such as buildings, bridges, roads, etc and the used concrete is the main waste product of them. Recycling of waste concrete to obtain the recycled concrete aggregates (RCA) for base and/or sub-base materials in road construction is a foremost application to be promoted to gain economical and sustainable benefits.

Reclaimed Concrete Material (RCM) is sometimes referred to as Recycled Concrete Pavement (RCP) or crushed concrete. It consists of high-quality, well-graded aggregates (usually mineral aggregates), bonded by a hardened cementitious paste. The properties of the processed RCM generally exceed the minimum requirements for conventional granular aggregates. Being a 100 percent crushed material; processed RCM aggregates "lock up" well in granular base applications and provide good load transfer when they are placed on weaker subgrade. The lower compacted unit weight of RCM aggregates compared with conventional mineral aggregates results in higher yield (greater volume for the same weight), and it is therefore economically attractive to contractors. For large reconstruction projects, on-site processing and recycling of RCM are likely to result in economic benefits through reducing of the aggregate hauling costs (FHWA,2016). Recycling concrete from deteriorated concrete structures would reduce the negative impact on the environment and increase sustainability of aggregate resources (Oikonomou ,2005; Hansen and Boegh ,1985)

The compaction characteristics (MDU and OMC) of RCA are statically significant: 19.4 to 20.8 5 KN/M³ for RCA at high OMC 8.7 to 11.8% (Kim *et.al.*,2007). The maximum dry density of the unbound base layer decreases with the increase of the recycled aggregate content (Taherkhani, 2015), table (1) typical properties of RCA.

Table (1): Typical Properties of RCA. (FHWA,2016)

Physical Properties	
Specific Gravity	2.2 to 2.5 (Coarse Particles)
	2.0 to 2.3 (Fine Particles)
Absorption	2 to 6 (Coarse Particles)
	4 to 8 (Fine Particles)
Mechanical Properties	
LA Abrasion Loss	20 – 45 (Coarse Particles)
Magnesium Sulfate Soundness Loss	4 or Less (Coarse Particles)
	Less than 9 (Fine Particles)
California Bearing Ratio (CBR)	94 – 148%

The concerning CBR of RCA between 94 and 184 (ACPA,1993), CBR-tests reveal good bearing capacity/shear strength: CBR=120-130 and high elastic stiffness values as compared to the ordinary gravel or the crushed rock materials. This implies a high stability and a good permanent deformation resistance of the RCA subbase (Aurstad *et.al.*,2006).

The stiffness of road base or subbase layers containing RCA or RAP has equal or higher Mr in comparison to that of the natural aggregates (Bejarano *et.al.*, 2003; Kim *et.al.*, 2007; Wen *et.al.*, 2008).

The CBR values obtained from the recycled concrete give significantly higher CBR values as compared with those values obtained from the ordinary subbase. This could be related to the amounts of dust materials which are usually higher in the ordinary subbase. The whole materials quality maybe another reason since the concrete material should have more resistance for the applied load as compared with that of the ordinary subbase materials (Hassoon and Obaidi,2014).

The properties of the recycled concrete aggregates and the mixed recycled aggregates suggest that these recycled materials can be used in unbound road layers to improve their mechanical behavior in the long term. The RCA CBR value was lower than its counterpart in natural subbase materials when it isn't soaking in water. Then it begins to increase higher than its counterpart in natural materials especially when the

time of soaking increases from 80% to 130% where the time of soaking remains 100% for natural. The main improvement for both recycled materials occurred at 28 days. This result appears to be associated with the presence of anhydrate cement in both samples. The RCA had the highest load capacity at 180 days; and the MRA had the lowest load capacity. (Laura *et.al.*,2015)

The remaining cement in the adhered mortar of the fine recycled concrete aggregates is the main cause of the self-cementing effect noticed on the subbases made with recycled aggregates. (Poon and Chan,2006; Shui *et.al.*,2008)

The structural coefficient which recommended at Florida Department of Transportation is 0.15 and the proposed one for RCA is 0.3, (FDOT,2000). the result of tested samples by (kuo *et.al.*,2002) was 0.34.

2-Methodology

The waste concrete cubes (produced after strength testing at the consultant bureau) are crushed to obtain different particle sizes. All cubes belong to the same group in order to ensure that they have the same composition, and they consist of cement al-jisser from the holly Karbala industries without any additives, filler or modifiers. The aggregates commonly used at the local region are fine aggregate from al-Najaf and the coarse aggregate from Al-Neba'ay. The portions of the components were 1cement: 1.5 fine aggregate and 3 coarse aggregate. The work consists of using samples of RCA with three groups, first group: samples graded as subbase layer (type B) middle limits but without filler, second group: samples have gradation of subbase layer (type B) mid. limits with lowest limit of filler (5%), and the third group: samples have gradation according to base layer mid. limits with (5%) lowest limit of filler, (grades sieves according to Iraqi specifications of roads and bridges SCRB 2003 and the filler is dust passing sieve number 200), and compared with the same specification requirements from bearing strength point of view. The experimental tests work plan consists of following:

1. Sieve analysis test according to AASHTO T-27.
2. Atterberg limits test according to AASHTO T-90.
3. Moisture-density relationship according to ASTM D 1557.
4. California Bearing Ratio (CBR %) according to ASTM D 1883.

Then analysis of laboratory test results in light of their acceptability by the related specifications standards.

3-Results and Discussions:

1- Sieve Analysis Test

The crushed concrete aggregate has an angular coarse aggregate with the maximum particles size 19 mm and a fine aggregate without materials passing sieve no.200 because there is no filler and the cement is hydrated. Figures (1) and (2) illustrate the grade of RCA as it is compared with base and subbase materials according to the Iraqi specifications limits for gradation.

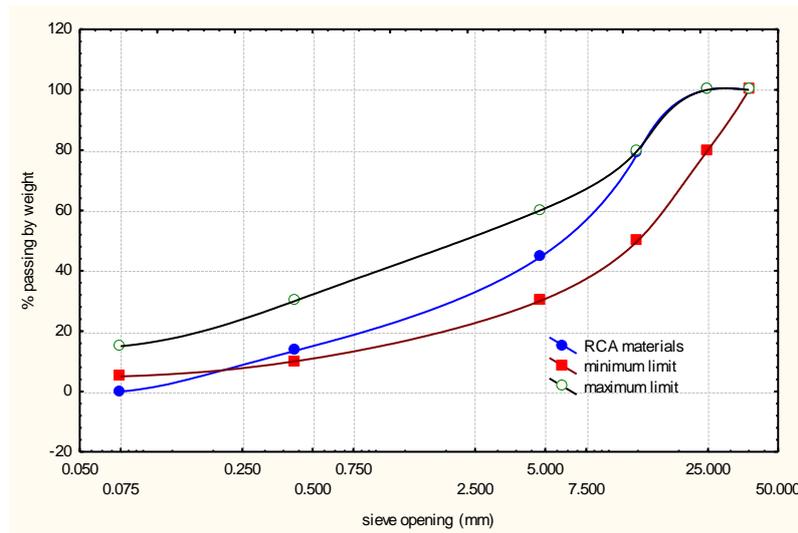


Figure (1): Comparison of RCA Materials Sieve Analysis Results with SCRB Requirements for Base Materials (SCRB, 2003- R7).

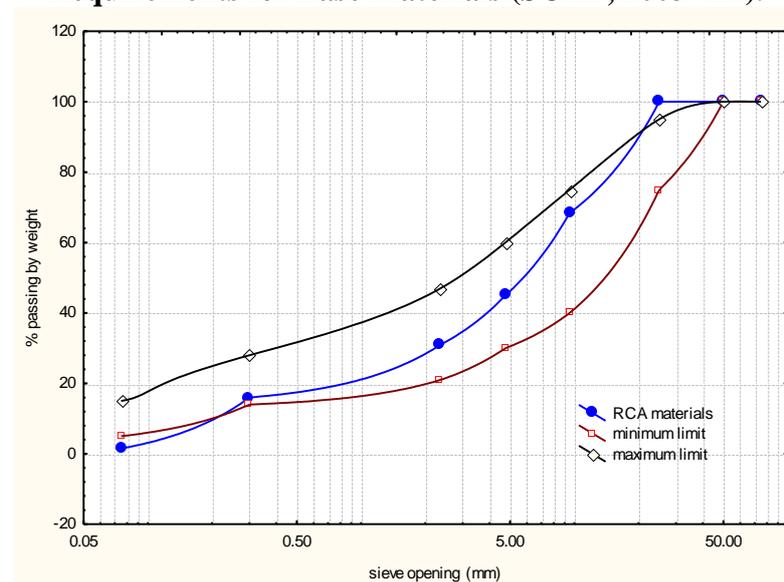


Figure (2): Comparison of RCA Materials Sieve Analysis Results with SCRB Requirements for Subbase Materials Type "B" (SCRB, 2003- R6).

2- Atterberg Limits

Material passing sieve no. 200 has 23 % liquid limit and its plasticity index is 4%.

3- Maximum Dry Density And Moisture Content Ratio

The results show that the maximum dry density of RCA graded as subbase layer but without filler was 2.07 gm/cm^3 with optimum moisture 3 % while when the filler is added it became 2.13 gm/cm^3 with optimum moisture 7%. When the grade is modified as base layer the density was 2.23 gm/cm^3 with optimum moisture 5%. The density increases with re-grading but it remains less than the ordinary materials.

4- California Bearing Ratio (CBR %) Test

First Group: The CBR value was 64 % as it is shown in figure (3); as compared with(Hassoon and Obaidi ,2014) local similar study, this result is close to their results of RCA satisfied with mid. gradation of Iraqi Specification requirements for subbase layer type B (with filler of mid. limits) and it is still comply with the Iraqi specifications for subbase layer. There is increment by 28% from the ordinary

materials. Group samples do not need to sieve long or to supply dusts to reduce clays and get little porosity.

Second Group: The RCA CBR value was 90 %. Figure (3) illustrates that taking the lowest value of dust range (5%) increases the CBR value and exceeds the results from samples which have mid. of filler percentage (10%) by 23%, is satisfied the Iraqi specification for subbase and base CBR. There is increment by 80% from the ordinary materials

Third Group: The CBR test result of RCA graded as mid. of the base course gradation limits but with 5 % dusts was 128 %. It satisfies the Iraqi specification of base course which is 80% with increment of 60% means the RCA has a good strength.

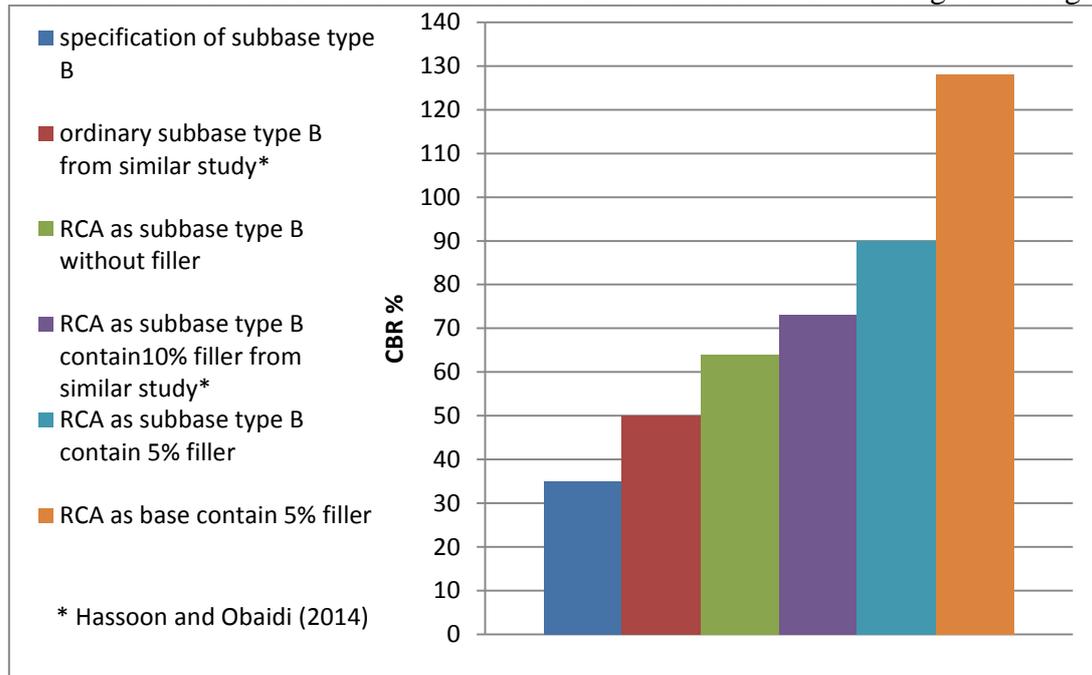


Figure (3): The Comparison among CBR Values.

CBR test's results obtained from the recycled concrete aggregate are still showing the highest values. This outcome might be due to the strength of the combined cement and aggregate in addition to the minimization the dust materials. Dusts in ordinary subbase materials are higher than they are in RCA but we need to a little amount of filler to RCA to increase the CBR value.

When use of the RCA as a subbase layer and according to AASHTO guide for design of pavement structures (AASHTO,1993); the(a_3) layer coefficient approximate 0.14 which minimizes the depth of subbase course. When the RCA is used as base layer the (a_2) is higher than 0.14 and the layer depth will be minimized too.

4-Conclusions:

1. The use of RCA improves the environment by reusing the waste solid materials; conserve the natural aggregate which has an economical benefit.
2. CBR test's results obtained from the recycled concrete aggregate still showing the highest values as compared with their counterpart in the ordinary local subbase materials, they show an increment by 28% when the RCA without filler and 80% when the RCA with 5% filler. The value of CBR are also high in the base course materials exceeds the requirement by 60%.
3. The values of CBR are agreed with the Iraqi specification for roads and bridges for using the later as base and/or subbase course layer.
4. To increase the CBR value, the RCA needs the lowest amount of materials that pass the sieve size (0.075) mm.

5. In light of the CBR values of using the RCA as a subbase layer, the depth of subbase will be minimized. When it is used as a base layer also its thickness will be minimized. There is no need to an additional layer; the RCA can be directly constructed on the subgrade with a determined depth then the asphalt wearing layer is added.

5-Recommendations:

1. It is recommended to use of RCA the correct gradation and the minimum value of materials passing sieve size (0.075) mm.
2. It's better to use the RCA as a pavement layer base and/or subbase.
3. We recommend to the state corporation for roads and bridges to use the unbound RCA as pavement alternative layer as possible as it can and to add it to the specifications.
4. Further studies on the RCA are recommended to find more characteristics to develop it as a pavement layer. Also recommended to study the blending of RCA with other material and to make store of literatures to future studies.

6-References

- American Association of State Highway and Transportation Officials AASHTO 2013, "**Standard Specifications for Transportation Materials and Methods of Sampling and Testing**", Washington DC. USA.
- American Concrete Pavement Association ACPA, 1993, "**Recycling Concrete Pavement**", American Concrete Pavement Association, Concrete Paving Technology, TB-014P. Skokie, Illinois, USA.
- ASTM ,2003, " standard test method: D 1557: **Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))**", Current edition approved Nov. 10, 2002. Published at January 2003. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States
- ASTM ,2005, " standard test method : D 1883-05: **Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils**", ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.
- Aurstad J., Aksnes J., Berntsen G., Dahlhaug J., Petkovic G. & Uthus N.,2006, "**Unbound crushed concrete in high volume roads – a field and laboratory study**", 5th International Conference on Research and Practical Applications Using Wastes and Secondary Materials in Pavement Engineering, John Moore University, Liverpool, UK.
- Bejarano, M. O., Harvey, J. T. and Lane, L., 2003, "**In-Situ Recycling of Asphalt Concrete as Base Material in California.**" Proc. 82nd Annual Meeting, Transportation Research Board, Washigton, D.C., 22.
- Federal Highway Administration Research and Technology, 2016, "**user guidelines for waste and byproduct materials in pavement construction-reclaimed concrete material**", Report FHWA-RD-97-148, 1200 New Jersey Avenue, SE / Washington, DC 20590 / 202-366-4000, USA.
- Florida department of transportation, 2000, "**Florida method of testing the lime rock ratio**", Florida DOT designation FM 5-515, Gainesville, FL, 18 pp.
- Hansen, T.C., and Boegh, E., 1985, "**Elasticity and Drying Shrinkage of Recycled-Aggregate Concrete**", ACI Materials Journal, V. 82, No. 5, pp. 648-652.
- Hassoon A. H., and Obaidi, J.T., 2014, "**The Use of Recycled Concrete as A Subbase Layer for Highways**", Al-Qadisiya Journal for Engineering Sciences, ISSN 19984456, Volume 7, Issue 3, Pages 273-277, www.iasj.net.

- Kim, W., Labuz, J. F. and Dai, S.,2007, "**Resilient Modulus of Base Course Containing Recycled Asphalt Pavement.**" Journal of the Transportation Research Board, No.2005, Washington, D.C., 27-35.
- Kou, S. C., Poon, C. S., and D. Chan, 2007,"**Influence of Fly Ash as Cement Replacement on the Properties of Recycled Aggregate Concrete**", Journal of Materials in Civil Engineering, Vol.19, No. 9, pp. 709-717.
- Laura Garach , Mónica López , Francisco Agrela , Javier Ordóñez , Javier Alegre , and José Antonio Moy, 2015, "**Improvement of Bearing Capacity in Recycled Aggregates Suitable for Use as Unbound Road Subbase**" materials, Granada 18071, Spain, pp 8804–8816. www.mdpi.com/journal/materials.
- Oikonomou, N.D., 2005, "**Recycled Concrete Aggregates**", Cement and Concrete Composites, V.25, No. 2, pp. 315-318.
- Poon, C.S., Chan, D. 2006, "**Feasible use of recycled concrete aggregates and crushed clay brick as unbound road sub-base**". Constr. Build. Mater., 20, 578–585.
- SCRB, 2003, State organization for Roads and Bridges, "**standard specifications for roads and bridges**", design and studies department, Ministry of housing and construction, Republic of Iraq.
- Shui, Z.; Xuan, D.; Wan, H.; Cao, B., 2008, "**Rehydration reactivity of recycled mortar from concrete waste experienced to thermal treatment**". Constr. Build. Mater. 22, 1723–1729.
- Taherkhani H., 2015. "**Evaluation of the Physical Properties of Unbound Base Layer Containing Recycled Aggregates**" International Journal of Environmental Science and Development, Vol. 6, No. 4, April 2015.
- Wen, H., Warner, J., Edil, T. and Wang, G., 2008, "**Laboratory Comparison of Crushed Aggregate and Recycled Pavement Material with and Without High Carbon Fly Ash**". Geotechnical and Geological Engineering, No.28, 405-411.