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# Developing an Environmentally Sustainable Hot Mix Asphalt Using Recycled Concrete Aggregates

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## ABSTRACT
Recycled concrete aggregate (RCA) is produced by properly crushing and sieving the demolished waste to obtain required size of aggregates that will substitute the need for virgin aggregates (VA). The economic and environmental benefits of using (RCA) from construction and demolition (C and D) activities have become clear in the recent years. The use of RCA in highway construction, especially in HMA, shall also contribute in the reduction of the consumption of VA as natural resources and the elimination of the stockpiles of concrete wastes.A series of experiments using recycled aggregate of various compositions from building rubble was conducted. This study evaluated the effects of replacing virgin aggregates (VA) by recycled concrete aggregates (RCA) on local HMA binder (3B). Blending of RCA with VA can lead to combined aggregates which pass the Egyptian standard specifications gradation. Increasing of RCA percentage in HMA leads to an increase in the (OAC), due to the high absorption of RCA and Stability of the HMA binder (3B) decreased but still within the Egyptian standard specifications by replacement of percentage of VA up to 80% by weight with coarse RCA in HMA binder (3B). The use of RCA significantly reduced the loss of stability, and reduced resistance to rutting for HMA binder (3B). Replacement up to 2% of powder by hydrated lime in HMA, leads to an increase in the Marshall Stability value increased.

## I. INTRODUCTION

Portland cement concrete has been used as one of construction materials for buildings and other structures. It primarily consists of cement, aggregate, and water. Aggregate is a major structural component of concrete and is typically obtained from natural stone or quarry. Recycling the concrete waste not only reduces the waste disposal problem, but also reduces the amount of quarrying of virgin aggregate (VA). Recycled concrete aggregate (RCA) is produced by properly crushing and sieving the demolished waste to obtain required size of aggregates that will substitute the need for VA. RCA are different from VA due to the amount of cement paste remaining on the surface of the recycled aggregates after undergoing the recycling process. The presence of cement paste increases the porosity of the aggregates, reduces the particle density, and thus, the quality and water absorption capacity of RCA may vary.

The economic and environmental benefits of using recycled concrete from construction and demolition (C and D) activities have become clear in the recent years. Significant use of RCA has been applied by many countries for local road construction, especially in hot mix asphalt (HMA). The early application researches are found in reports from United States (Ciesielski and Stanley 1994) and Netherlands (Hendricks and Janssen 2001). It has been reported that RCA in HMA affected the volumetric properties and performance of HMA.

As recycled concrete can be used within the same suburban area, it can lead to a decrease in the energy consumption related to transportation with a consequent improvement in the quality of air as a result of reducing the emissions of the mobile source and thus reducing the use of VA. It is worth to mention that there is no testing specification for the suitability of using RCA as road pavement materials in Egypt. The present study is considered as an introductory step for the expected Egyptian specifications. The use of RCA in highway construction, especially in HMA, shall also contribute in the reduction of the consumption of VA as natural resources and the elimination of the stockpiles of concrete wastes.

## II. OBJECTIVES OF THE STUDY

The purposes of this study are:

- Investigate the optimum percentage of RCA that can be used in HMA binding course.
- Investigate the impact of using different percentages of RCA on unit weight, flow, and stability of HMA binder (3B).

- Produce dense graded mixtures that resistance to rutting and cracks using different percentages of RCA.

## III. MATERIALS

### 3.1 VIRGIN AGGREGATE (VA):

Attaka aggregates have been used in the preparation of the asphalt concrete specimens. The physical properties of the aggregate are illustrated in table 1 and the gradation of the used aggregate is identical with the standard specifications (AASHTO T-27).

X-Ray diffraction analysis of the virgin aggregates is shown in Figure 1.

Table (1): Results of the physical properties of VA

| Test | Virgin Aggregate | Specifications AASHTO |
|---|---|---|
| Bulk specific gravity g/cm3 (AASHTO T-85) | 2.448 | 2.4 – 2.9 |
| Absorption % (AASHTO T-85) | 2.506 % | ≤ 5% |
| Los substance in water % | 0.25 % | ≤ 1 % |
| Los Anglos Abrasion %(AASHTO T-96) | 24.68 % | ≤ 40% |

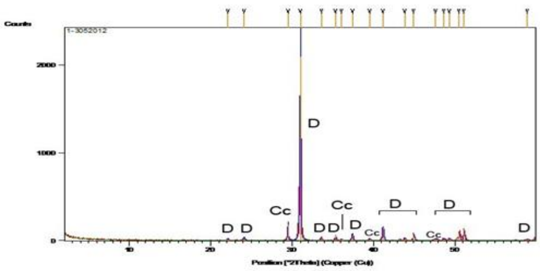


Figure 1: X-ray diffraction analysis of virgin aggregates (VA)

### 3.2 ASPHALT CEMENT:

The asphalt cement is 60-70 penetration grade and the penetration is (65) at 25 $^{o}$C after 5 seconds. It has specific gravity 1.02 with kinematic viscosity of 395 centistokes and ductility of 100+ cm. It is produced locally by E-Nasr Company, Suez governorate, Egypt.

### 3.3 RECYCLED CONCRETE AGGREGATE (RCA):

Demolished concrete obtained from slab of building was constructed in 2005, to produce RCA; concrete is broken into large chunks, and then transported to small crusher. Any remaining steel in the debris is removed and concrete debris is further crushed into smaller aggregate size required for construction, and then washed using water. The physical properties of the aggregates are illustrated in table 2 and the gradation of the used aggregates was identical with the standard specifications (AASHTO T-27) while x-Ray diffraction analysis of the RCA is shown in Figure 2.

Table (2): Results of the physical properties of RCA

| Test | Virgin Aggregate | Specifications AASHTO |
|---|---|---|
| Bulk specific gravity g/cm3 (AASHTO T-85) | 2.337 | 2.0 – 2.5 |
| Absorption % (AASHTO T-85) | 5.79 | 4 – 8 % |
| Los substance in water % (AASHTO T-85) | 0.75 | ≤ 1 % |
| Los Anglos Abrasion Value %(AASHTO T-96) | 43.6 | ≤ 40 - 45% |

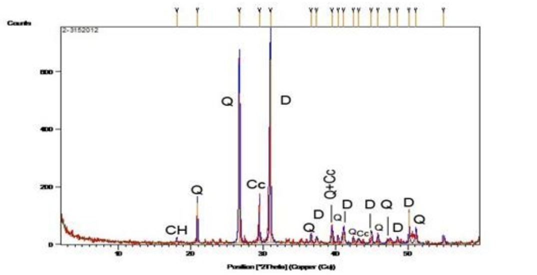


Figure 2: X-ray diffraction analysis of recycled concrete aggregates (RCA)

## IV. EXPERIMENTAL PROGRAM

The experimental program was divided into two stages. In the first stage, control samples "RCA = 0%" and samples with different percentages of RCA were prepared and tested. In the second stage, samples of the optimum percentage of RCA, which added as a percentage of coarse aggregate obtained from Marshal Test and control sample, were tested. Figure (3) shows a schematic diagram of the experimental program.

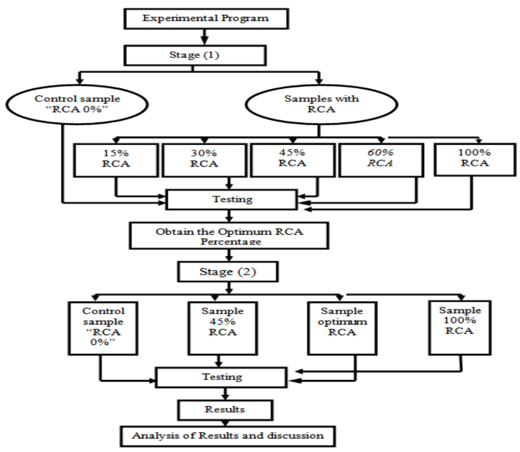


Figure (3): Schematic diagram for the experimental program

STAGE 1: CONTROL SAMPLE "RCA = 0%"

The mix design was carried out using 5.5% asphalt contents, which is the optimum bitumen content for control specimen. All mixes were prepared according to the Egyptian standard assuming heavy traffic. The percentage of dry mix, gradation of dry mix (3B), and the average values of unit weight, Marshall Stability and flow properties were determined and verified the Egyptian standard.

STAGE 1: SAMPLES WITH RCA

Five different percentages of coarse RCA (15%, 30%, 45%, 60%, and 100%) were blended with VA**.** The gradation of dry mix (3B) for all different percentages, and the average values of unit weight, Marshall Stability and flow properties were determined and illustrated in Table 3.

Table (3): The average values of unit weight, Marshall Stability and flow properties for HMA binder (3B) with different percentage of coarse RCA

| %AC | 5.5 % | 5.5 % | 5.5 % | 5.5 % | 5.5 % |
|---|---|---|---|---|---|
| % Coarse RCA | 15 | 30 | 45 | 60 | 100 |
| % Coarse VA | 85 | 70 | 55 | 40 | 0 |
| Unit weight t/m3 | 2.259 | 2.269 | 2.217 | 2.224 | 2.17 |
| Stability (lb.) | 1940.3 | 1880.0 | 1864.3 | 1682.3 | 1501 |
| Flow (0.01) in | 11.53 | 12.83 | 13.8 | 14.1 | 13.83 |

STAGE 2: STRIPPING PERFORMANCE TEST

Four control specimens and four specimens with 60% RCA replacing virgin coarse aggregate were prepared to evaluate the performance of asphalt mix (3B), and the results of loss of stability test of control specimens and specimens of 60% RCA were determined and illustrated in Tables 4.

Table (4): Retained Stability "AASHTO T-165"

| AC% | 5.5% | 5.5% | 5.5% | 5.5% |
|---|---|---|---|---|
| Sample | 0 % RCA | | 60 % RCA | |
| Unit weight t/m3 | 2.313 | 2.310 | 2.21 | 2.22 |
| Stability (Ib) after 24 hr in water At 60 ℃. | 1681 | 1681 | 1255 | 1255 |
| Stability (Ib) after 30 min in water at 60 ° C | 2084 | 2022 | 1604 | 1676 |
| Retained stability | 0.82 | | 0.77 | |

STAGE 2: WHEEL TRACK PERFORMANCE TEST

One control specimen and another specimen with 60% RCA replacing virgin coarse aggregate were prepared to evaluate the performance of asphalt mix (3B), and the results of wheel tracking test of control specimen and specimen of 60% RCA were determined and illustrated in Tables 5. The test was carried out at 60 ºC for one hour producing 2520 passes.

Table (5): Wheel Tracking Test results

| Test time (min) | Rutting depth (mm) | specifications |
|---|---|---|
| Control Mix | 3.91 | ≤ 7 mm |
| 60 % RCA | 5.90 | ≤ 7 mm |

STAGE 2: EFFECT OF HYDRATED LIME

In order to improve the performance of HMA (3B) made of 100% RCA, hydrated lime was used with an amount of 1 and 2 % by weight of aggregates, based on previous literature. Hydrated lime was also added with amount of 1 and 1.5 % in HMA (3B) made of 60% RCA.The engineering properties of three compacted samples of HMA (3B) made of 100% RCA with 1 and 2% hydrated lime are presented in table 6, the results show that the stability value of HMA (3B) increases with increasing the % of hydrated lime.

Table (6): effect of hydrated lime

| Type | 0 % RCA | | 60 % RCA | |
|---|---|---|---|---|
| % hydrated lime | 1 | 2 | 1 | 1.5 |
| Unit weight t/m$^3$ | 2.253 | 2.328 | 2.305 | 2.332 |
| Average stability (lb) | 1700 | 1878 | 2063 | 2337 |
| Average flow flow(0.01) in | 13.43 | 13.1 | 11.7 | 12.4 |

Also, the results showed that the stability value increases with increasing of the % of hydrated lime.

## V. RESULTS AND DISCUSSION

### 5-1 RESULTS OF STAGE (1)

The control sample "RCA = 0%".was prepared with 100% VA and asphalt content of 5.5%. The mix was designed to meet the local specifications of HMA binding course (3B). The volumetric and mechanical properties (OAC, stability, flow, unit weight and air voids) were determined on three compacted specimens of HMA "RCA = 0%". The table shows that the stability value of HMA "RCA = 0%" is equal to 2088.3 lb which is more than 1800 Ib, and satisfies the Egyptian specifications.

Coarse and fine virgin aggregates were partially and totally replaced by five different percentages of RCA amounting to 15%, 30%, 45%, 60%, and 100% to obtain HMA. The gradations of the mixes were designed to meet the local specifications of HMA binding course (3B). The bulk density, stability and flow tests were determined for triplicate compacted specimens of HMA (3B) made of the different RCA (15, 30, 45, 60 and 100%). The engineering properties estimated for the respective samples are presented in (Table 3). The results show that the stability values of HMA (3B) made with the RCA contents of 15 to 60% are higher than 1600 Ib and satisfy the Egyptian specifications. The individual values are equal to 1966.3, 1880, 1864.3, 1682.3Ib for 15, 30, 60 and 80% of RCA replacement respectively. The stability value of only the sample with 100% RCA is equal to 1501 lb; which is less than 1600 Ib, thus it does not comply with the Egyptian specifications.

## 5-2 RESULTS OF STAGE (2)

The loss in stability and wheel tracking tests (WTT) were conducted on the control specimen (100% VA) and specimen with 60% RCA. The results of (WTT) are presented in Figures 4 and 5 and Table 5.

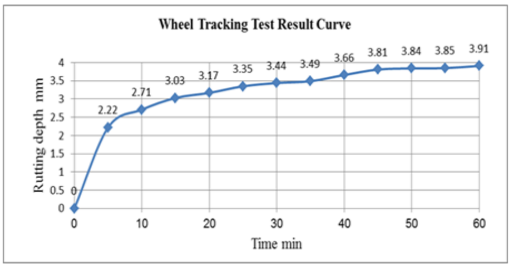


Figure 4: wheel tracking test result for HMA (3-B) “RCA = 0%”

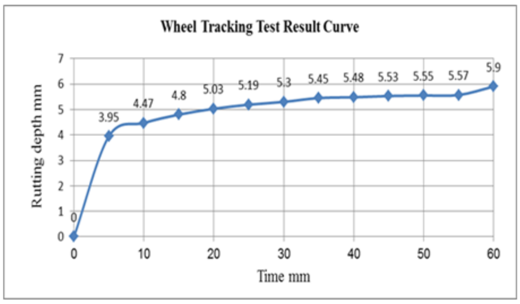


Figure 5: Wheel Tracking Test result for HMA with 60 % RCA

The stability of the control specimens immersed in water at 60 ºC for 30 min and 24 hr were 2053 (lb) and 1681 (lb) respectively, see Table 4. The loss of stability was 18% which is less than the maximum allowable limit of 25% in the Egyptian specifications. The results of WTT shown in Table 6 indicated that the maximum rutting depth for the specimens conditioned at 60ºC is 3.91 mm ≤ 7 mm which is less than the maximum allowable limit, figure 4.

On the other hand, the stability of the specimens with 60% replacement of RCA% immersed in water at 60 ºC for 30 min and 24 hr were 1640 (lb) and 1255 (lb) respectively, see Table 5. The loss of stability was 20% which is less than the maximum allowable limit of 25% in the Egyptian specifications. The results of WTT shown in table 7 indicated that the maximum rutting depth for the specimens conditioned at 60ºC is 5.91 mm ≤ 7 mm which is less than the maximum allowable limit, figure 5.

In order to improve the performance of HMA (3B), hydrated lime was used with an amount of 1 and 2% or 1% and 1.5%, by weight of aggregates for the control specimen and the specimen with 60% of RCA respectively. Engineering properties of both mixes are presented in table 8, and figure 6. Table 9 showed that, the stability of HMA (3B) increased with an increase in the percentage of hydrated lime and reached to 2063, 2337 Ib for 1 and 1.5 % hydrated lime respectively, which exceeds the minimum values cited in the Egyptian specifications.

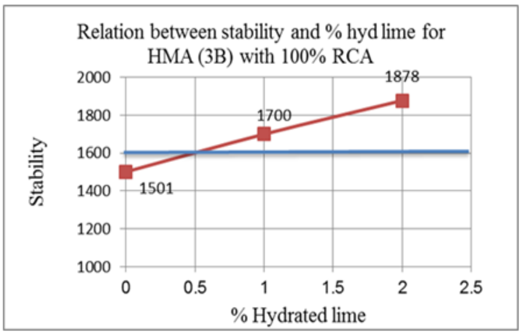


Figure 6: Relation between stability and % hydrated lime for control specimen

A summary of the results obtained from the investigation carried out on the effect of replacing VA by RCA in HMA (3B) is illustrated in Figure 7 which shows the change in the stability of the HMA with an increase the RCA percentage. It is easy to estimate the maximum replacement ratio of the RCA from the intersection point of the curve representing the stability measured with the Egyptian specification, which is 80% replacement. Although the flow increased with an increase in RCA, it is remained between the upper and lower limits, Figure 8. Also, the unit weight generally decreased with an increase in RCA replacement, figure 9. The OAC increases with an increase in the RCA percentage.

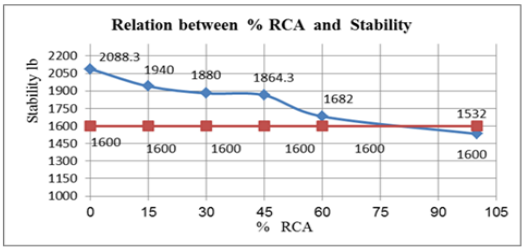


Figure 7: Relationship between stability (lb) and % RCA

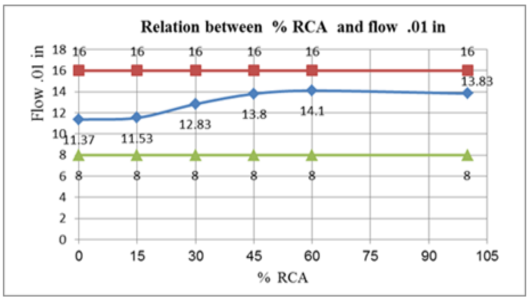


Figure 8: Relationship between flow0.01 in and % RCA

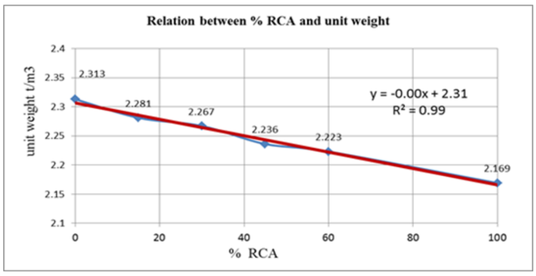


Figure 9: Relationship between % RCA and unit weigh

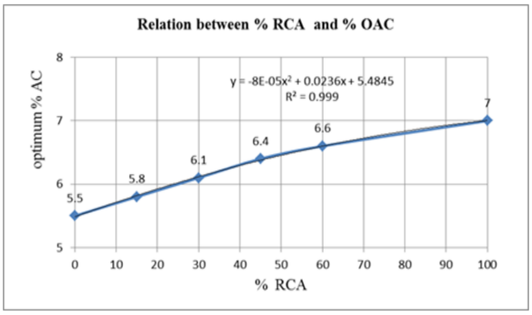


Figure 10: Relationship between % RCA and % AC

The modified behaviour of the HMA as a result of replacement of VA with RCA is attributed to the nature and composition of both materials. The VA is composed of almost pure dolomite ~ 98 % with traces of calcite, figure 1. As these aggregates are supplied directly from natural quarries, it is not expected to find components other than those detected by XRD. In other word no clays or fines or any other amorphous materials are detected in the X-ray. The properties of these aggregates shall be based on the behaviour of the dolomite phase solely. Accordingly the stability of the mix satisfies the specification which limit value is cited to be 16000Ib.

On the other hand, the RCA are multi-components aggregates obtained from recycled concrete. In general, the traditional concrete mix contains around 15-18% cement, in addition to sand and coarse aggregates. The X-ray diffractogram of the RCA indicates the presence of quartz sand as fine aggregates and dolomite as crushed stone coarse aggregates, figure 2. The identification of the calcite presence in the diffractogram is explained by the carbonation of portlandite in the recycled concrete as a result of its processing, traces of portlandite are still detected in the sample. Other phases presented in the RCA are the calcium silicate, sulfoaluminate, sulfoaluminoferrite hydrates and possibly gypsum. Some of the calcium silicate hydrates might have carbonated to silica gel and calcium hydroxide.

All these phases shall affect the water absorption, density and stability of the HMA. The use of portlandite (calcium hydroxide or hydrated lime) improved the properties probably as a result of reacting with silica gel to produce weaker phases of the calcium silicate hydrates in a way similar to the reaction of the latent hydraulic (pozzolanic materials).Due to the presence of these phases, the density of the RCA decreases and its porosity increases which leads to a higher water absorption and thus decreases the unit weight. The fine component favours the flow. The amount of AC needed to saturate the RCA mix raises due of the possible higher surface area of the fine constituents. Consequently the loss in stability increase with increasing the RCA content. The performance for the wheel tracking and the max rutting depth for HMA binder (3B) “RCA = 0%” is slightly higher than the control mix but lay within the specification. It has been well established that hydrated lime reacts with acid components of bitumen to produce beneficial changes that contribute to the creation of high performance asphalt mixes. Hydrated lime contribution to asphalt mixtures is a reduction in the rate of oxidative hardening. It was found that increasing the percentage of RCA decreased the VMA and VFA of the mixes.

## VI. CONCLUSIONS AND RECOMMENDATIONS:

The application of building rubble collected from damaged and demolished structures is an important issue. Aggregate reclaimed from demolition concrete with fully hydrated cement can contain a significant amount of adhered mortar. After crushing and screening, this material can serve as recycled aggregate in road construction. A series of experiments using recycled aggregate of various compositions from building rubble is conducted. The test results show that the building rubble can be transformed into useful recycled aggregate through proper processing. Using unwashed recycled aggregate in HMA will affect its stability.

The effect will be more obvious at higher asphalt content. When the recycled aggregate is washed, these negative effects are greatly improved. This study evaluated the effects of replacing virgin aggregates (VA) by recycled concrete aggregates (RCA) on local HMA binder (3B). One source of RCA were procured and used in this study. The evaluation consisted of three aspects: effects of RCA on mix design, effects of RCA on performance of HMA binder (3B), and effects of hydrated lime on the performance of HMA binder (3B) with RCA. Based on the experimental evaluation, the following conclusions could be observed:

Stage 1

- RCA used in this study is highly absorptive and the porous structure leads to low specific gravity.
- Blending of RCA with VA can lead to combined aggregates which pass the Egyptian standard specifications gradation.
- Washing of RCA is required to remove the dusts, using recycled water in washing reduce the cost of producing RCA.
- Different percentages of RCA from 15% to 100% were blended with VA in HMA binder (3B) but the OAC was changed.
- The increase of use RCA percentage in HMA leads to an increase in the (OAC), due to the high absorption of RCA.
- Stability of the HMA binder (3B) decreased but still within the Egyptian standard specifications by replacement of percentage of VA up to 80% by weight with coarse RCA in HMA binder (3B).

Stage 2

- The use of RCA significantly reduced the loss of stability, and reduced resistance to rutting for HMA binder (3B).
- Replacement up to 2% of powder passed sieve No. 200 by hydrated lime in HMA-binder (3B), leads to an increase in coarse RCA up to 100% and the Marshall Stability value increased.

**Recommendation for further study**

- Using fine RCA in HMA may has economically feasible.
- Crushing concrete in site may be more economic
- Evaluate the use of RCA in road construction especially as base and subbase
- Testing of other sources of RCA for using as aggregates in HMA.
- Developing standard specifications that control the use of RCA in road construction.
- Conducting similar tests on other asphalt mixes to collect more experience in dealing with RCA.
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