Blending of recycle concrete aggregates for use in base course construction by concrete method

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Abstract-A research paper program is conducted to study the use of using recycled concrete aggregate (RCA) mixed with traditional limestone aggregate (LSA) which is currently being used in base or sub base course of road. Since it is checked the effect of mixture variables on the mechanical properties of cement treated recycled aggregates(CRTA) is tested. This test is conducted to find out the compressive and tensile strengths based on mixture parameters. The results defined the adding of RCA enhance the mechanical properties of the RCA and the unconfined compressive strength (UCS) is used as quality indicator. Variables influencing the UCS such as cement content, curing time, dry density play important roles to determine the performance of CTRA.

Key Words: Recycling, Concrete Aggregate, Demolished concrete

I. INTRODUCTION

Aggregate is one of the most vitally important materials in use for concrete production as it profoundly influences concrete properties and performance. Regarding aggregate usage in concrete, a conservative estimate is that at least 4.5 billion tons of concrete aggregates per year are consumed worldwide. This figure is assumed to represent total aggregate production, including usage in concrete and road base.

The above inevitably impacts on the environment due to the great huge quantity of general and construction waste materials or from building demolition sites generated in developed countries. The research conducted for the Industry Commission Report indicated that about 3 million

There is severe shortage of infrastructural facilities like houses, hospitals, roads etc. in India and large quantities of construction materials for creating these facilities are needed. The planning Commission allocated approximately 50% of capital outlay for infrastructure development in successive 10th & 11th five year plans. Rapid infrastructural development such highways, airports etc. and growing demand for housing has led to scarcity & rise in cost of construction materials. Most of waste materials produced by demolished structures disposed off by dumping them as land fill. Dumping of wastes on land is causing shortage of dumping place in urban areas. Therefore, it is necessary to start recycling and re-use of demolition concrete waste to save environment, cost and energy.

Central Pollution Control Board has estimated current quantum of solid waste generation in India to the tune of 48 million tons per annum out of which, waste from construction industry only accounts for more than 25%. Management of such high quantum of waste puts enormous pressure on solid waste management system.

The total quantum of waste from construction industry is estimated to be 12 to 14.7 million tons per annum out of which 7-8 million tons are concrete and brick waste. According to findings of survey, 70% of the respondent have given the reason for not adopting recycling of waste from Construction Industry is "Not aware of the recycling techniques" while remaining 30% have indicated that they are not even aware of recycling possibilities.

II. Materials

A. Natural aggregate

Limestone aggregate LSA taken from the general Nile company of desert roads is used in this research as granular layer material. The origin of the limestone aggregates is EL-Suez area, in the northeast Egypt. Fig. 1 illustrates the grading curves of LSA within the specification limits for highway works in the Egypt. LSA contains an amount of fines about 5% with 19% liquid limit and 14% plastic limit.

B. Recycled concrete aggregate

To produce RCA, Portland cement concrete is broken up and crushed. The major intrinsic material properties that limit the use of RCA are specific gravity, absorption, soundness (resistance to environmental conditions such as chemical

and physical weathering), gradation, and contaminant solubility and the potential for groundwater contamination. The major external factors that limit the use of RCA are cost, state specifications, and environmental regulations [6].
The grain size distribution for RCA is presented in Fig. 1.The amount of fines in this aggregate reaches to about 4.8%.

C. Portland cement

Portland cement is used as a treatment material for the granular mixtures. The properties of this cement are given in Table 1.

D. Standards requirements for granular mixtures

The base/subbase courses must be made according to a specified aggregate gradation and requirements to insure adequate stability under repeated loads. Table 2 shows the different specifications required according Egyptian code for rural and urban highways.

III. Experimental work

A. Aggregate properties

The physical properties of the used natural and recycled aggregates are summarized in Table 3. The natural aggregates have the highest density value, while crushed concrete has the highest water absorption value. Indeed, the high amount of adhered mortar attached to RCA particle leads to a decrease in particle density and an increase in the water absorption.

B. California bearing ratio

CBR tests are performed on untreated compacted blended mixtures of RCA and LSA as a measure of granular soil strength. The mixtures are compacted in the test mold of 15.24 cm diameter and 12.7 cm height; moreover, 4.54 kg surcharge weight was applied.

C. Plate load test preparation

The test box contain square of 0.5m-0.5m-0.5m box. The aggregate is spread in five layers of 10.0 cm thickness in the model and compacted man- ually by cylindrical concrete hummer weighted about 10 kg un- der OMC of each mixture. Then, sand cone test is carried out on the surface of the final compacted aggregate layer to check the relative density and make sure that it greater than 95% according to the standards of highways Egyptian Code. The surface of compacted aggregates is leveled; then, the loading circular steel plate of 16 cm diameter and 2.5 cm thickness is centered. A contact pressure of 0.5 N/mm^2 on asphalt surface layer is considered. Using the BISAR-linear elastic program, the vertical stress reaches to the base coarse considering 5.0 cm asphalt wearing coarse and 5.0 cm asphalt binder coarse decreases to 0.35 N/mm^2

D. Permanent deformation

To utilize current mechanistic–empirical methods of pavement design, material properties of the pavement system (pavement layer, base, sub base, and sub grade) are needed to analyze its response to traffic-type loading. Knowledge of material properties allows for the prediction of stresses and strains developed in the pavement system. For flexible pavement design, the prediction of failure is based on determining the plastic deformation in base layer. The plastic deformation for blended base aggregate mixtures can be obtained from the plate test after the third loading cycle.

E. Unconfined compressive strength

For cement treated mixtures, compressive strength tests (ASTM C 39) are conducted where the preliminary cement content by weight or by volume was selected. The unconfined compressive strength (UCS) values for aggregate mixtures are obtained by testing cylindrical specimens of dimensions 150 diameters with 300 mm height (length/diameter ratios of about 2.00) using steel molds. The cast specimens are kept in ambient temperature for 24 h; after that, the samples are wrapped in double layers of wet burlap where placed in moist environment for curing. The average unconfined compressive strength of the cement treated specimens after 1, 3, 7, and 28-days moisture curing time is obtained.

IV. Tensile strength

The tensile strength of cement treated recycled aggregate is al- ways considered as a significant material parameter for design pavement structures. The reason is because the bottom of the treated aggregate layer suffers the tensile stress. In general, flexural beam tests and indirect tensile tests have been employed to evaluate the tensile strength of treated aggregate

A. Flexural strength

Designers of pavement use a theory based on flexural strength (FS). Therefore, laboratory mix design based on flexural strength tests may be required. The flexural strength is ex- pressed as modulus of rupture where determined by stander test method (ASTM C-78).

B. Indirect tensile strength

The indirect tensile strength (ASTM C-496) is conducted. A standard test cylinder specimen (300 150 mm diameter) is placed horizontally between the loading surfaces of compres- sion testing machine. Due to this compressive loading, an ele- ment lying along the vertical diameter is subjected to a vertical compressive stress which acting for about 1/6 depth. The larger portion of cylinder is subjected to uniform tensile stress acting horizontally which acting for about 5/6 depth.

V. Laboratory Results

A. Moisture–density relationship

Modified proctor compaction test (ASTM D698) is conducted on RCA and LSA blended mixtures. The

maximum dry den- sity (MDD) and optimum moisture content (OMC) are illus- trated in Table 4. The natural aggregates have the highest MDD by about 10% and the lowest OMC. Since the grading of each aggregates is similar, this difference is mainly attributed to the physical properties of natural aggregates which has the highest particle density and is less porous.

B. California bearing ratio

can be calculated after the third loading cycle from Eq. (1), where the uniform

applied pressure(P) equals 0.35 N/mm^2 and the radius of circular plate (a) equals 80 mm. As obtained in Table 5, the RCA has high resil ient modulus more than LSA where with increasing the RCA content in the blended mixtures, Mr values increase.

Plastic deformation is related to the stiffness properties of the material that affect the fatigue cracking of overlying asphalt layers, whereas the gradual accumulation of permanent deformations, although very small during each loading cycle, could lead to the collapse of the structure due to excessive rut- ting. Therefore, the

Table 1 Properties of natural and recycled aggregates.

Property	RCA	Limestone	Egyptian standard
Unit weight (kg/m^3)	2546	2660	Relative density > 95%
Los Angeles abrasion (%)	33.5	40	50 max
Angle of internal friction (°)	47	23	–
Bulk specific gravity	2.4	3.1	ASTM C-127
Water absorption (%)	2.25	1.05	10 max
Poisson's ratio	0.25	0.35	–
Plastic index (PI)	3.5	5.0	Max L.L 30% Max P.L 8%

Table 2 Properties of the Portland cement.

Properties	Value	Chemical properties	Value
Specific gravity	3.15	CaO (%)	58.32
Initial setting time (min)	150	SiO2 (%)	26.56
Final setting time (min)	185	MgO (%)	1.12
Volume expansion (mm)	2.0	Fe_2O_3 (%)	3.89
Compressive strength (MPa)		Al_2O_3 (%)	6.58
2 days	22.0	SO_3 (%)	3.32
7 days	38.7	LOI (%)	1.25
28 days	46.8	Specific mass (kg 10^3/m^3)	2.96
		Specific surface area (mm^2/g)	39.78

CBR test is carried out in both unsoaked and 4-day soaked conditions where the results are summarized in Fig. 3. Accord- ing to the highway Egyptian standards, the minimum CBR values for sub base and base courses are 25% and 50%, respectively. In unsoaked case, the LSA has the highest CBR value (85%) where the CBR value gradually decreases as the RCA content increases.

C. Plate loading test results

In the first load cycle, the cumulative deformation increases rapidly with increasing the vertical pressure. When the total load releases and the material takes a sufficient time to re- bound, one part of vertical deflection is return and the residual part is remained as shown in Fig. 4 for limestone aggregate which considered as an example for the plate loading test re- sults. The resilient modulus

conventional road pavement design approach is based on providing adequate thickness of layers in such a way that the pavement structure does not experience shear failure and that unacceptable permanent deformations occur in each layer. On the basis of this evidence, an appropriate understanding and characterization of plastic deformation behavior of granular materials is needed in order to perform a successful pavement design [8]. Table 5 shows the total deformations as well as the plastic deformation ratios (Pdr) that means the accumulated plastic deformation divided on the to- tal deformation after the third loading cycle. In fact, the 100% RCA sample donates minimal Pdr (45.5%). The addition of LSA to the RCA samples aides in increasing the amount of plastic deformation.

Table 3 Plate loading test results for granular blended mixtures.

Blended name	Total deformation (mm)	Plastic deformation ratio (Pdr) (%)	Mr (MPa) (N/m m^2)
Mix RA0	1.12	74.0	34.5
Mix RA25	1.08	66.5	39.3
Mix RA50	0.92	53.7	43.5

D. Cement treatment for coarse aggregate

The proportioning design method of cement treated recycled base aggregate CTRA mixture that applied in the last decades is tentative. Therefore, the problem of designing a CTRA mixture is the lack of an effective procedure that allows predicting its mechanical properties from mixture parameters like the mix composition and the characteristics of components [4]. This paper herein studies the influence of mixture variables on the mechanical properties of CTRA

E. Resilient modulus and plastic deformation for mixtures

The blended recycled aggregate mixtures are tested under plate loading test to obtain the resilient modulus and plastic deformation ratio Fig. 5 illustrates a valuable improvement in Mr values due to cement treatment where it shows that the improvement percentage (IV) increases as the RCA increases. The treated MixRA75 achieved the maximum Mr with IV reaches to 35%.

F. Unconfined compressive strength

The UCS is generally acknowledged as an important indicator of the mixture quality of treated aggregate. A number of mixture variables influence its compressive strength are investigated such as the cement content, mixture dry density, moisture content, fine materials amount, and curing time.

G . *Influence of moisture content*

. From the regression equations, the multiple R^2 for treated recycled aggregate with moisture content from 7.0% to 9.0% and treated limestone aggregate with moisture content from

6.5% to 11.0% are high. However, note that there is a big scatter for the regression equation of treated RCA when its moisture con- tent ranges from 9.0% to 14% (R^2 = 0.7909).

H. *Influence of curing time*

The curing age is another important factor affecting the UCS. The UCS development with the curing time at cement content 5% and fine amount 5%. Tensile Strength results

I. Flexural strength

For flexural strength, which is an important material parameter when designing pavement where it has been shown from previous literatures that the flexural strength (FS) of CTRA are about 10–20% of the UCS [7].

Table 4 Compaction test result for untreated mixtures.

Blended name	Materials	Optimum moisture content (OMC) (%)	Maximum dry density (MDD) (t/m^3)
Mix RA0	100% LSA	11.0	1.984
Mix RA25	75% LSA + 25% RCA	9.5	1.900
Mix RA50	50% LSA + 50% RCA	10.6	1.820
Mix RA75	25% LSA + 75% RCA	12.3	1.780
Mix RA100	100% RCA	14.7	1.740

Table 5 Flexural and indirect tensile strengths.

Blended treated mixtures	Curing days	Indirect tensile strength (ITS) (MPa)	Flexural strength (FS) (MPa)	FS/UCS (%)
Mix RA0	7	0.242	0.295	14.5
	28	0.42	0.471	15.0
Mix RA25	7	0.238	0.281	11.4
	28	0.376	0.452	13.6
Mix RA50	7	0.232	0.272	7.6
	28	0.357	0.428	10.8
Mix RA75	7	0.225	0.265	7.3
	28	0.322	0.41	10.0

Considering these test results shown in Table 8, it is remarkable that with increasing the recycled aggregate content or decreasing the curing period, the flexural strength as well as the ratio (FS/UCS) obviously decreases.

J. Indirect tensile strength

The indirect tensile strength (ITS) is calculated according to Eq. (3) for blended granular mixtures treated with 5% cement. As shown in Table 8, concrete recycled aggregate shows only about 70% strength when compared to natural limestone aggregates. Moreover, with increasing the recycled aggregate in the mixture, the ITS decreases.

K. Conclusions

Most recycled aggregates produced in Egypt contain large amounts of crushed concrete. Thus, detailed research on the application of recycled cement treated aggregates to build the subbase or base layers of roads is therefore needed. It is found that the mechanical properties of cement treated mixtures are influenced and determined by a number of variables, including cement content, curing time, and fine material amount. Based on the laboratory test results, the following conclusions are drawn:

With increasing the concrete recycled aggregate to natural limestone aggregate, the maximum density and CBR values of untreated mixtures decrease and the optimum moisture con- tent increase. The soaked CBR values for recycled aggregate lie within Egyptian allowable limits. Moreover, the concrete recycled aggregate mixtures donate minimal plastic deformation while the maximum resilient modulus is achieved at MixRA75. The cement treatment leads to a valuable improvement in the resilient modulus reaches to 35% at MixRA75 and in plastic deformation reaches to 60% at MixRA100.

A linear relationship can be given to approximate the relationship between the UCS and the cement content where the UCS of concrete recycled aggregate is obviously higher than it for limestone aggregate especially with increasing cement content. The dry density or the degree of compaction is an important factor to determine the UCS of treated aggregate where a linear relation correlates them. The UCS increases, while the density decreases with the increase in the RCA content.

There exists a threshold moisture content (9%) that critically influences the UCS development of CTRA. Up to this moisture content, a strong regression equation is achieved between dry density and UCS. Beyond this level a big scatter for the regression equation is obtained. On the other hand, the UCS approximately increases linearly with the curing time for both treated recycled and natural aggregates. The relationship between them is illustrated with three adjust- able variables thus it produces more accurate estimation.

With the increase in fine material amount, the strength ratio (FS/UCS) increases within limits from10% to 20%. The LSA obtains strength ratio higher than it for RCA where the recycled aggregate shows about 75–80% of the flexural strength for natural aggregates and about 70% of the indi- rect tensile strength for natural aggregates. The curing per- iod has no obvious effect on the strength ratio. Generally, the building demolition debris in the base or subbase layers can be transformed into useful recycled aggregate through proper processing for pavement designs.

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