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Assessment of Recycled Concrete aggregates as an Aggregate for Roads

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ABSTRACT

The work discusses the incorporation of recycled aggregates (RA) in road pavement materials considering asphaltic concrete mixes and base or sub-base layers. Replacement of coarse RA instead of coarse natural aggregate (NA) in asphalt mixtures was investigated. It was found that the use of coarse RA in asphalt concrete mixes were complied with the Marshall technical specifications, but it may have insufficient durability due to their high susceptibility to water action which was evaluated using the retained stability test. These asphalt mixtures may be used in the underneath layers of road pavements such as base course layers, but it should be avoided in wearing or water proofing in the upper layers of pavements. On the other hand, the analysis of the RA materials required for using it as base or sub-base in roads were successfully in the range of specification limits. These materials could be incorporated and declared in the Egyptian specifications as an aggregate for roads.

KEYWORDS: recycled aggregate, natural aggregate, base and sub-base courses.

1. INTRODUCTION

Demolition of old and deteriorated buildings and traffic infrastructure, and their substitution with new ones is frequent phenomenon today in a large part of the world. Some reasons for this situation are changes of purposes, structural deterioration, rearrangement of a city and natural disasters (earthquake fire and flood). The common method of managing this material has been through its disposal and landfills. In this way, huge deposits of construction waste are created, consequently becoming a special problem of human environment pollution. A possible solution of this problem is to recycle demolished concrete and produce an alternative aggregate. Figure 1 illustrates the appearance of recycled aggregate.[1]

The aim of this work was to determine the strength characteristic of RA for the application in road pavement materials such as base course, sub-base course and a coarse aggregate in asphaltic concrete mixtures.

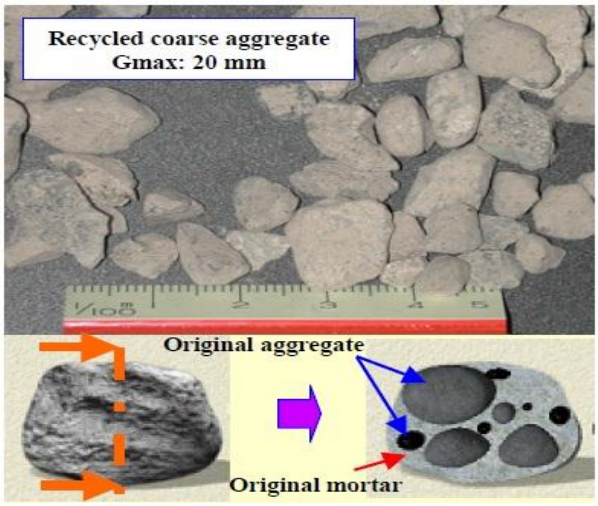

Figure 1: The appearance of recycled aggregates.[1]

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2. EXPERIMENTAL WORK

2.1. Asphaltic Concrete Mixtures

The hot asphaltic concrete mix was commonly used in the asphaltic layers of pavement. To investigate the effect of using recycling concrete aggregate, two different asphalt concrete mixes were selected differing in coarse aggregate type. A mix was composed of virgin coarse aggregate and the other was composed of recycled coarse aggregate. Both mixes were composed of natural sand as fine aggregate, limestone powder as mineral filler and bitumen of 60-70 penetration grades. The Marshall method of mix design was used to determine the optimum bitumen content for both mixes.[2] Loss of stability test was used to assess these mixes.[3] Recycled concrete aggregate was prepared and refined locally in lab (figure 2). The properties of recycled and natural aggregates are given in table 1.

Figure 2: Preparation of recycled concrete

Table 1: Properties of recycled and natural aggregates.

Test properties	***Measured values***		***Spec. limits***
	Natural coarse aggregate	*Recycled coarse aggregate*	
Crush resistance (Los Angeles test)%	27	47	**AC** max. 40 **Base** max. 50
Water absorption after 24 hours%	1.33	5.24	Max. 10
Specific gravity gm/cm^3	2.54	2.38	2-3

Specific gravity of natural sand =2.57

2.1.1. Marshal Method of Mix Design:-

For both mixes the aggregates were collected and separated by sieves into the required aggregate sizes to produce asphalt concrete binder course according to the required gradation given in table 2.

Table 2: Gradation of aggregates used in a binder coarse Asphaltic concrete mix.

Sieve size	1 in	3/4 in	3/8 in	No 4	No 8	No 30	No 50	No 80	No 200
Gradation %	100	87	57	40	28	12	7	5	2
Specification limits	100	75-100	45-70	30-50	20-35	5-20	3-12	2-8	0-4

The standard Marshal procedure was used to carry out the mix design. To determine the optimum binder content, standard Marshal Specimens were prepared with bitumen contents varying from 4% to 6% in increments of 0.5%. The specimens were prepared for bitumen content, and were subjected to density-void analysis and stability-flow test (Figure 3).

2.1.2. Loss of Stability Test:-

The loss of stability test was conducted on Marshal Specimens that were prepared using the optimum binder content obtained from the mix design for both mixes. The test was performed as per ASTMD 1075 specifications[4]. A total of six specimens for each mix were prepared, of which three specimens were conditioned in water at 60°C for 30 minutes, whereas for each mix the other three specimens were conditioned at 60°C for 24 hours before testing for loss of stability.

3. RESULTS AND DISCUSSION

3.1. Marshall Test Results

Marshal test results are shown in Table 3 and 4. The test results for unit weight, stability, flow, percentage air voids, (VMA) voids in mineral aggregates and voids filled with bitumen were plotted against percentage bitumen content for both mixes (Figures 4-9).

Figure 3: Marshall testing for asphalt concrete mixtures.

Table 3: Marshall Test Results for Virgin Aggregate Mix (Mix-1).

Asphalt %	Unit weight gm/cm^3	Stability 1bs	Flow mm	AV %	VMA%	VFB%
4.0	2.279	1950	2.8	5.80	14.76	60.7
4.5	2.305	2190	3.1	4.26	14.44	70.4
5.0	2.309	2150	3.8	3.48	14.78	76.3
5.5	2.300	1810	4.3	3.00	15.41	80.5
6.0	2.296	1700	5.2	2.59	16.1	83.8

Table 4: Marshall Test Results for Recycled Aggregate mix (Mix-2).

Asphalt %	Unit weight gm/cm^3	Stability 1bs	Flow mm	AV %	VMA%	VFB%
4.0	2.145	1410	2.9	7.11	15.52	54.1
4.5	2.174	1750	3.0	5.24	14.83	64.6
5.0	2.181	1790	4.3	4.258	14.95	71.5
5.5	2.190	1680	5.2	3.160	14.99	78.9
6.0	2.175	1590	6.3	3.290	16.10	79.5

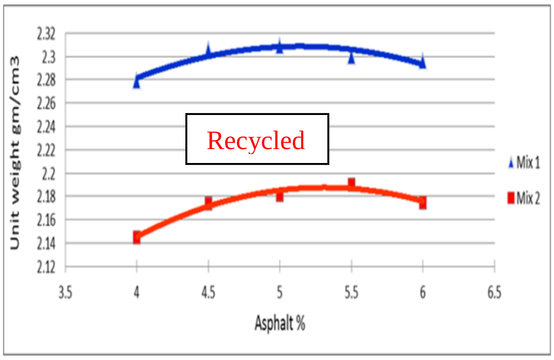

Figure 4: Unit weight results for both asphaltic concrete mixes

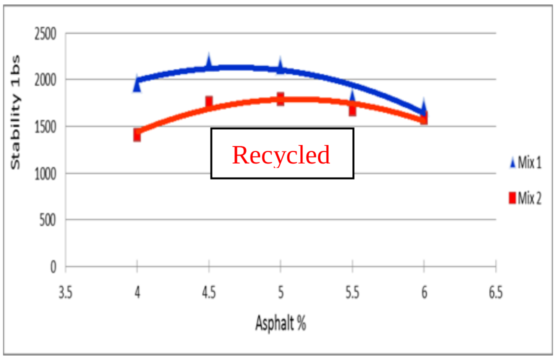

Figure 7: Stability results in Marshall test for both asphaltic concrete mixes

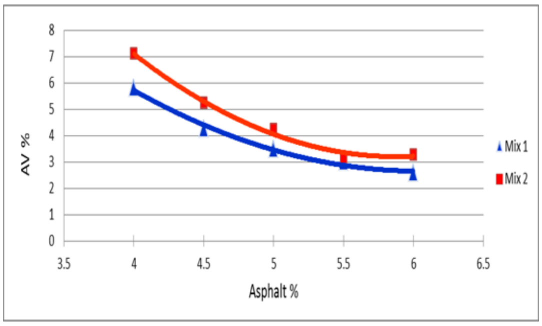

Figure 5: Air void results for both asphaltic concrete mixes

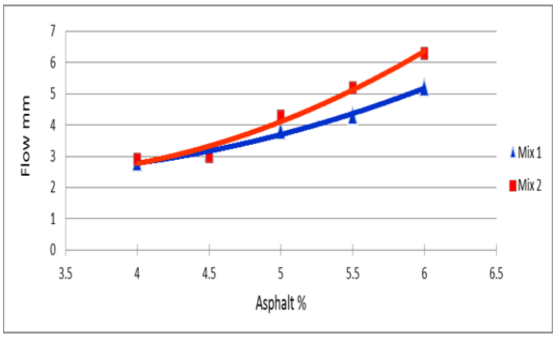

Figure 8: Flow results in Marshall test for both asphaltic concrete mixes

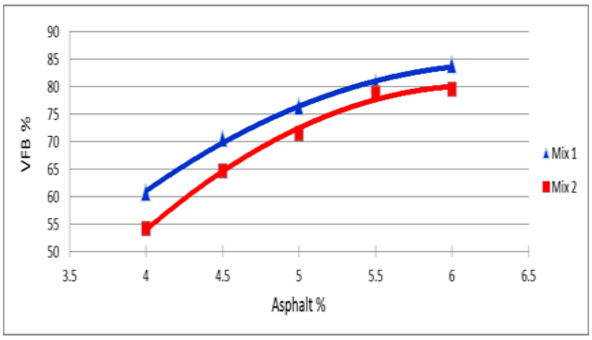

Figure 6: Voids filled with bitumen results for asphaltic concrete mixes

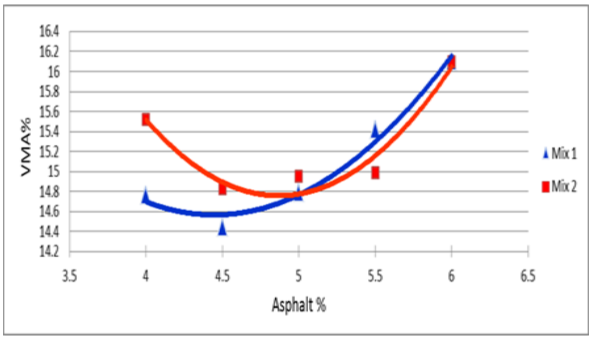

Figure 9: Voids in mineral aggregates results for asphaltic concrete mixes

The optimum binder contents were 4.73, 5.1 for mixes one and two respectively. Table 5 summaries the mix properties at the optimum binder content for both mixes considering the current specifications. The results for both mixes were considered to be in the acceptable range. Although that, there is a little decrease has appeared in the mix containing recycled aggregates for stability and bulk densities and a slight increase in percentage air voids and voids in mineral aggregate. These results were accounted for by the increase in angularity of particles and the decrease in recycled aggregate densities.

3.2. Loss of Stability Test Results

A loss of stability test is presented in table 6. The results indicated that the loss of stability was 16% for mix-1 containing virgin aggregate, which is less than the maximum allowable limit of 25% as per specification, whereas the loss of stability was 29% for mix-2 containing the recycled aggregate (table 6).

It is very important to emphasize that these mixtures may cause durability problems, since the retained stability values are clearly insufficient. The reasons for these poor values may be the coarse RA contains some cement mortar particles that may crumble and break during the compaction process owing to impacts received by the samples. Also, the high absorption of water causes easy breakage of the cement mortar that is attached to the coarse RA. These properties encourage bitumen displacement by the water, giving rise to the stripping of the aggregates and a generalized loss of mechanical properties. These results were confirmed by other researchers. Perez and Medina (2011)[5] concluded that hot mix asphalt materials designed with coarse RA meet the Marshall parameters for low volume roads and present poor stripping behavior which has a negative effect on the durability of the mixtures since the retained strength ratio values are clearly insufficient because of the break of mortar particles during the compaction process and the high absorption of water which leads to stripping of the aggregates and loss of mechanical properties. Jiking and Wang (2012)[6] indicated that the recycled aggregates had a negative effect on moisture resistance of asphalt mixtures. Millis and You (2010)[7] indicated that RCA is capable of serving as a useful replacement in hot mix asphalt roadways where traffic loads were minimal. The results also show that permanent deformation on the roadway is unlikely to be a problem under this low traffic condition with RCA use of up to 75%. It is recommended that a certain amount of RCA in hot mix asphalt is acceptable for low volume roads.

But Ahmed and Al-Fadala[3] indicated that the asphalt concrete produced using an aggregate of demolition waste can meet the requirements of local Kuwait specifications considering the loss of stability test. These results may be accounted for by the quality of the recycled aggregates used in their research.

Finally, it could be concluded that hot mix asphalt materials designed with coarse RA could be used successfully in the underneath layers of road pavements such as base course layer. Whereas, these mixes should be avoided for using it as wearing or water proofing courses in the upper asphaltic layers of pavements.

3.3 Base and Sub-base Layers

The other pavement layers include base course, sub-base course, and subgrade. To study the validity of the recycled aggregates to be used in the above layers, the quality control tests required for these recycled materials were conducted. A comparison between the obtained result values of the tests and their requirements according to the Egyptian code were executed. Some of these tests were; CBR test, Los Angeles abrasion test, liquid and plastic limits, sieve analysis, absorption, and dissolving in water. The results of CBR test for four specimens of recycled aggregate materials are given in table 7. The following table 8 gives the results of the required quality control tests for the recycled aggregate materials and the specification limits for each pavement layer.

The results indicated that the properties of the recycled aggregates were within the specification limits. So, these RA could be used as an acceptable material for base or sub-base layers in road pavements. These results were confirmed by other research. Celeen (2007)[8] indicated that the USA uses about 85% of recycled aggregate as base or sub-base courses. Most of states in USA declared the use of RA as base, or sub-base course in their specifications (figures 10-12). So, RA materials could be incorporated in Egyptian specifications for using it as base or sub-base materials.

Table 5: Marshall Test Results of optimum bitumen content.

Specimen properties	Mix-1 virgin, opt bit. 4.73%	Mix-2 recycled, opt bit. 5.1%	Egyptian specification of roads
Unit weight (gm/cm^3)	2.32	2.18	_
Stability (1bs)	2200	1750	≥ 700
Flow (mm)	3.5	3.9	2-4
Air voids (%)	4.0	4.3	3-8
Voids in mineral aggregates (%)	14.7	15.0	≥ 14
Voids filled with bitumen (%)	74	73	70-85

Table 6: Loss of Stability Test Results for both mixes.

	Virgin aggregate	Recycled aggregate	Egyptian specification of roads
Stability	2100	1760	≥ 700
Submerged Stability	1764	1250	--
Stability loss	16%	29%	≤ 25%

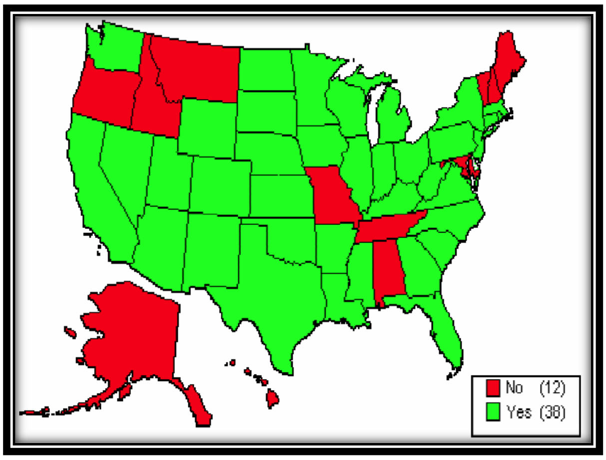

Figure 10: States Recycling Concrete as an Aggregate Base.[8]

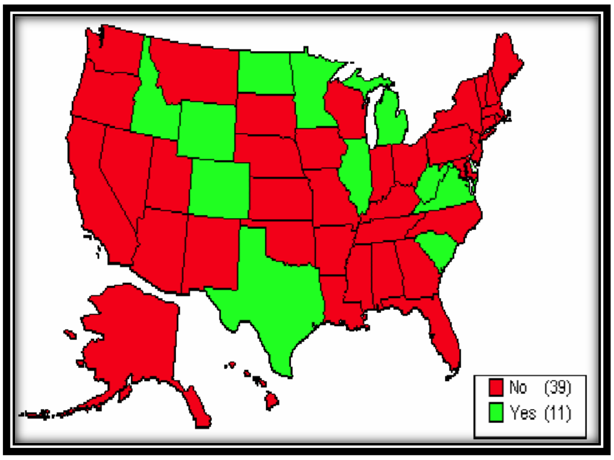

Figure 11: States Recycling Concrete as Aggregate for PCC.[8]

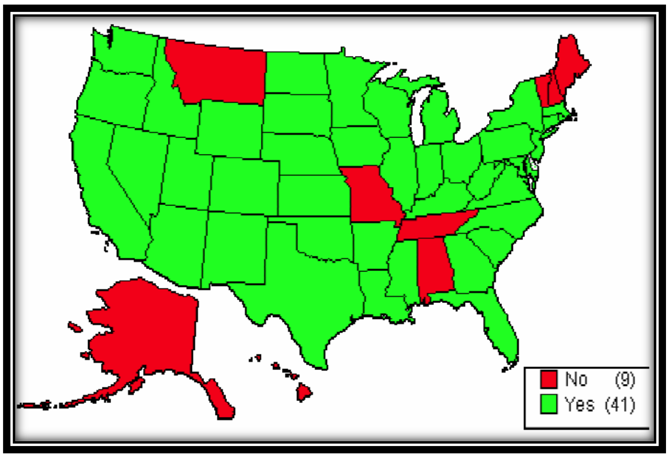

Figure 12: States Recycling Concrete as an Aggregate.[8]

Table 7: CBR values for the different recycled aggregate gradation curves

Sieve size	Percentage passing			
	1	2	3	4
1	90	100	100	100
3/4	75	100	100	100
1/2	62	98	100	100
3/8	55	88	100	100
4	43	65	98	100
8	34	50	78	100
16	25	34	60	75
30	18	24	42	49
50	10	16	28	30
100	7	9	12	16
200	2	4	5	9
Soaked CBR %	70	60	40	21

Swelling = 0

Table 8: Egyptian Code Specification limits for the granular materials used in base course, sub-base course, and subgrade.

Material property	***Egyptian Specification of roads***			***Experimental results of recycled materials***
	Base layer	Sub-base layer	Subgrade layer	
Abrasion lost by Los Angeles test %	50%	-	-	47%
California Bearing Ratio % CBR%	60%	25%	10-20%	20-80% for different gradations
Swelling %	None	None	None	None
Dissolve in water %	5%	10%	-	2%
Absorption %	10%	10%	-	6.18
Liquid limit %	30%	30%	-	N.P.
Plasticity index	8%	8%	-	N.P.
Muck and peat or blocks of clay	None	None	None	None
Gradation	Within specified gradation			

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

1. The properties of hot asphaltic concrete mixes designed with recycled coarse aggregates considering the current specifications were in the acceptable range. The retained stability values of these mixes were clearly insufficient which may cause durability problems. So that, it could be used successfully in the underneath layers of road pavements such as base course layers. These mixes should be avoided in the upper layers as wearing or water proofing courses.
2. The analysis of the recycled aggregate materials required for using it as base or sub base in roads were successfully in the range of the specification limits. So that, it could be incorporated and declared in the Egyptian specifications of road materials.

4.2. Recommendations

1. In Egypt, in order to encourage the use of recycled aggregate as well as reduce the environmental impact of the concrete waste and save sustainable energy, it is necessary to have a plant for crushing the demolished concrete waste.
2. The use of recycled aggregate material in road works should be included in the Egyptian Standard Specifications.

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