EVALUATION OF RECYCLING ASPHALT PAVEMENT HOT MIX

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ABSTRACT

The concept of recycling asphalt has been in existence for over 75 years. However, only in the last 20 years asphalt recycling has been widely accepted, where many countries becoming increasingly involved in the various forms of recycling of pavement materials.

The main purpose of this study is to evaluate some old asphaltic concrete surface course of flexible pavement in the urban roads of Alexandria for potential of being recycled. Laboratory tests including grading, Marshall Properties and indirect tensile strength are carried out on the mixes containing recycled and natural materials. Test results show that the tensile strength of mixtures containing 75% recycled materials and 25% virgin materials have higher values than those mixed with virgin materials.

Keywords: Recycled materials, Marshall test, Creep test, Indirect Tensile Strength Test and Economic Evaluation.

INTORUDUCTION

Recycling existing materials is the best solution to some of the problems facing transportation administrations. Recycling can contribute to environmental preservation by reducing the amount of new materials required for highway use. Thus, a corresponding reduction is possible in environmental problems of mining the new material and manufacture the products, in addition to avoiding the problems associated with disposition of the old pavement[1,2,3].

The recycling of the materials in the existing roadway has become popular and economically feasible. The asphalt materials that have been constructed contain valuable aggregate and asphalt of some type that could be salvaged. If these materials were recycled, the material supply of the aggregate, which is becoming scarce, could be conserved and haul distance for both the new aggregate and disposal could be reduced. Reduction of haul distance will naturally reduce fuel consumption and this could prove beneficial along with reduced minimis[4]. Another item of concern is disposal which is often difficult and expensive because of environmental requirements. Also, the addition of asphalt overlays on the aged surface develops indirect extra cost for raising the level of sewer manholes and curbs, specially in urban area. Considering these factors, both economical and ecological benefits could be desired from recycling[5].

The main purpose of these studies is to compare the use of some old asphaltic concrete of surface course in Alexandria urban road for their potential of being recycled and the traditional method of paving the surface course layer.

TESTING PROGRAM TO EVALUATE THE HOT-MIX RECYCLED ASPHALT MIXTURES

Virgin mixtures containing virgin asphalt cement grade 60/70 and mixes grade (maximum size 9.5 mm for dense mixtures) according to ASTM D 3515 for surface course were compared with the recycled and virgin-recycled mixtures. Salvaged and virgin aggregate combinations in recycled mixtures were adjusted to have the gradation of 9.5 mm for surface course. This adjustment was not complicated because the gradation of salvaged aggregate was within 9.5 mm for surface course specification limits, and the virgin aggregate gradation was selected to be the specification of 9.5 mm for surface course specification [6]. The fine mixes prepared were designated as 100% Recycled materials (R), 75% R and 25% Virgin (V), 50%R and 50% V, 25% R and 75% V and 100% V. All mixtures had the same aggregate gradation (maximum size 9.5 mm). Four asphalt contents were used in mix preparations. These percentages of asphalt cement were 5, 5.5, 6, and 6.5 percent by total weight of dry aggregates.

EXTRACTION TEST

Five samples were taken to evaluate the asphalt content of salvaged mixes. The amount of asphalt present was determined and the salvaged aggregate obtained from extraction was characterized by sieve analysis, specific gravity, water absorption and percentage of abrasion. From the results of these tests, it can be seen that the asphalt content in recycled asphalt pavement was found to be 5.2% an average by weight of old asphaltic mix. Figure 1 shows the gradation of salvaged aggregate. The mixture according to the American Society for testing and materials specification [6] for dense surface course with maximum size 9.5 mm was also included in this figure for comparison purposes and for future determination of the feasibility of the salvaged aggregate for use as a high-quality of hot asphaltic concrete mixtures. The recovered aggregate consisted mainly of crushed dolomite as coarse aggregate (material retained on sieve size 4.75 mm) and sand as a fine aggregate (material passing from sieve size 4.75 mm and retained on sieve size 0.075 mm). The sieve analysis of the salvaged aggregate indicates a gradation that is within the specification for dense mixtures with maximum size of aggregate 9.5 mm for surface source according to ASTM D 3515 [6].

SPECIFIC GRAVITIES OF SALVAGED AGGREGATE

To evaluate the specific gravities of Salvaged aggregate after extraction, it was divided this aggregate into three size fractions:-

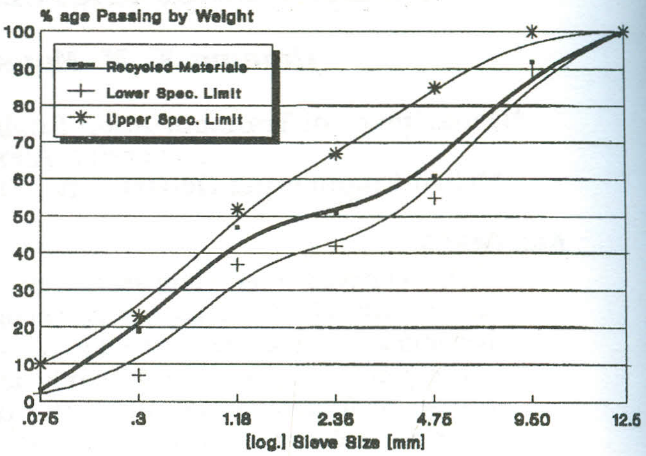

Figure 1 Average gradation of aggregate extracted from asphalt pavement

1- A portion passing from 19.5 mm and retained on 2.36 mm sieve size (Coarse Aggregate)
2- A portion passing from sieve size 2.36 mm and retained on sieve size 0.075 (Sand)
3- A portion passing from sieve size 0.075 mm (mineral Filler)

The results of specific gravities and absorption of each type of fraction are given in Table 1.

Table 1 Physical properties of salvaged and virgin aggregates

Properties of Materials	C. Agg		Fine Agg.		M. Filler	
	S.	V.	S.	V.	S.	V.
Bulk Specific Gravity	2.23	2.38	2.54	2.60	2.65	2.62
Water Absorption [%]	1.0	3.2	-	-	-	-
% age of Abrasion						
After 100 rev.	4.4	5.2	-	-	-	-
After 500 rev.	8.6	9.4	-	-	-	-

VIRGIN AGGREGATE USED IN THIS STUDY

Crushed dolomite and sand obtained form Alexandria-Cairo desert road were selected to represent the coarse and fine aggregates for the virgin materials. Limestone dust was used as a mineral filler.

PRELIMINARY VIRGIN AGGREGATE TESTS AND RESULTS

The virgin aggregates were tested by carring out sieve analysis, specific gravity, abrasion water absorption. The results of sieve analysis for coarse aggregate, fine aggregate and mineral filler are given in Table 2. Also, the gradation of the three aggregates together with final blend matching the asphalt specification limits are given in Table 2 [6].

Table 2 Gradation and mix of virgin materials, aggregate, sand and mineral filler

Sieve Size [mm]	Agg 65%	Sand 31%	M. F. 4%	Mix. 100%	Specification Limits (9.5mm)
12.5	100	100	100	100	100
9.5	90	100	100	93.5	90 - 100
4.75	60	100	100	74	55 - 85
2.36	30	100	100	54.5	32 - 67
1.18	12	90	100	39.7	37 - 52
0.3	3	40	100	8.35	7 - 23
0.075	0	2	75	3.62	2 - 10

The percent wear after 100 and 500 revolutions are presented in Table 1 togther with the results of specific gravities of coarse aggregate, fine aggregate and mineral filler. Moreover, Table 1 shows the percent of water absorption for both virgin and salvage aggregates. It was evident that the percent of water absorption for the salvage aggregate was lower than that for virgin aggregate. This phenomenon was expected because salvage aggregate is locked by previously absorbed asphalt and did not allow the same amount of water intrusion as in virgin aggregate.

VIRGIN ASPHALT CEMENT USED IN THIS STUDY

An asphalt Cement produced by Alexandria Petroleum Company in Alexandria City was used in this investigation. This type of asphalt was evaluated in Laboratory to measure the penetration and flash point. The average penetration was 64 and flash point was determine to be 315 °C.

MARSHALL TEST

Preparation of Marshall Test Specimens

The specimens used in Marshall test were prepared at five levels of recycled aggregates addition 0%, 25%, 50%, 75% and 100% by the total weight of aggregate. Also, four levels of asphalt content, 5%, 5.5%, 6% and 6.5% by the total weight of mix, were prepared for each level of recycled material added. These specimens were prepared using the standard Marshall compactor (75 blows on each side).

Marshall test results for recycled and virgin materials mixes are shown in Table 3 at optimum asphalt content (6 percent). The characteristics of Marshall test are discussed in the following sections.

Table 3 Marshall properties at optimum asphalt content (6%)

Marshall Properties	Percentage of Recycled Materials (R) [%]				
	0%	25%	50%	75%	100%
Stability (KN)	4.2	6.8	8.2	9.4	9.2
Density (gm/ cm³)	2.28	2.26	2.27	2.26	2.28
Flow (mm)	2.5	2.5	2.8	3.2	3.8
Air Voids (%)	3.6	2.52	2.26	1.68	1.07

Marshall Stability and Flow

Marshall stability and flow are measures of the ability of a mix to resist plastic flow. This test method is still an interbreed part of mix design criteria for selection of asphalt contents for asphaltic concrete mixes. Table 3 presents the Marshall stability values for virgin and recycled mixtures.

It can be seen that in general, Marshall stability were sensitive to recycled asphalt content in the various mixtures. The optimum asphalt content corresponding to maximum stability and other Marshall properties was found to be 6.0% by weight of total mixes for recycled and virgin aggregates. From Table 3 it can be noticed that mixtures of 75% recycled and 25% virgin aggregates provided the highest Marshall stability values. However, at all levels of asphalt content the stability values of recycled virgin mixes are higher than those of virgin aggregate mixes, as seen in Figure 2. In general, the higher stability values of the recycled mixes are attributed to the hardness of the aged asphalt.

Flow values, for all mixtures, ranged between 2.5 mm to 3.8 mm. On the other hand, Marshall flow values are within specification limits (2-5 mm). However, there is no obvious reasons for the high flow property for the mix containing 100% recycled material. The relation between the flow value and the percentage of asphalt in the different mixtures is given in Figure 3.

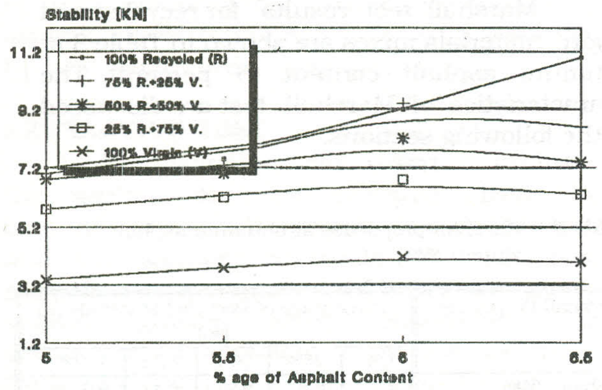

Figure 2 Percentage of asphalt content-stability for different mixtures

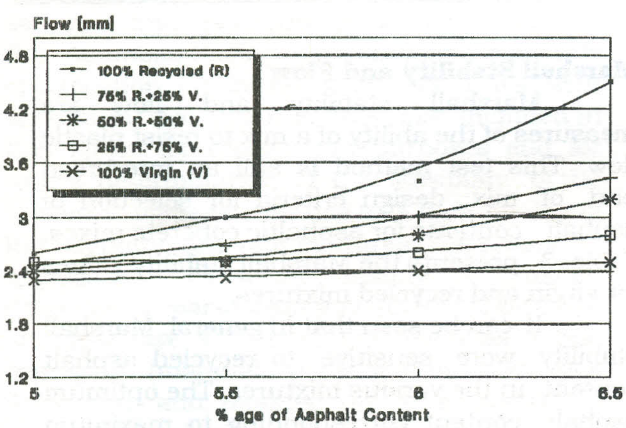

Figure 3 Percentage of asphalt content - Flow for different mixtures

Density

Table 3 illustrates the density values at optimum asphalt content (6 %) and different percentages of recycled and virgin materials. It can be noticed that no significant change in density values at different percentages of recycled materials. Therefore it can be concluded that the densities for both recycled and virgin mixes are almost equal. Figure 4 shows the relationship between the density values and the percentages of asphalt content at different mixtures.

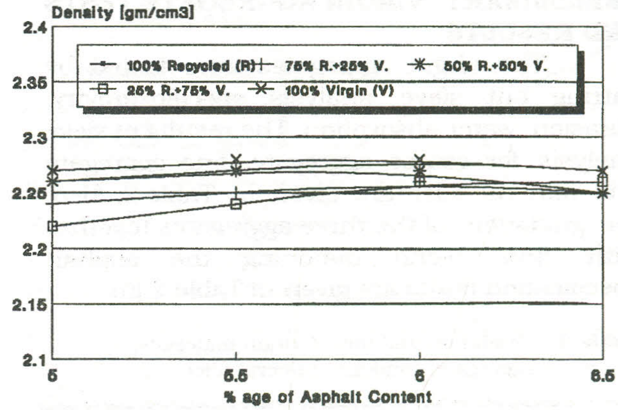

Figure 4 Percentage of asphalt content - Density for different mixtures

Air Void Percent

Air void percent at different concentration of recycled materials and asphalt is shown in Figure 5. From this figure it can be seen that the recycled percent is more effective on the air void percent. The percent of air void is reduced from 3.8% to 2.2% by decreasing of recycled materials in mixtures from 100% to 0% at lower value of asphalt content(5%). However, at higher value of asphalt content (6.5 percent), the percent of air void for all mixtures are almost equal and has a value of about 0.4 percent.

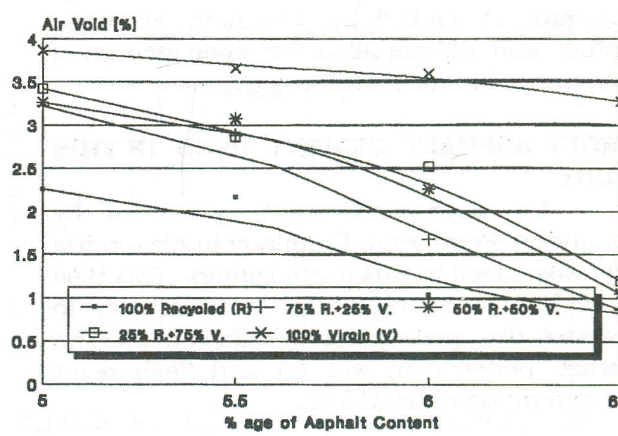

Figure 5 Percentage of asphalt content - Air void percent for different mixtures

CREEP TEST

The unconfined creep test was made by using the consolidation equipment with some modification Marshall specimens were produced at different proportions of recycled materials and at optimum asphalt content produced by Marshall test (6 percent). This test was performed at room temperature under total load of 80 kg, corresponding to vertical stress of σ=0.099 N/mm^2, for 2 hours duration. At the end of the test, the total vertical deformation was measured and the creep stain (ε) as well as the stiffness (S) were calculated from the following equations[7].

Creep Strain (ε) =($\Delta h/h$) x 1000 [‰] (1)

Stiffness (S) = (σ/ε) x 1000 [N/mm^2] (2)

where,

Δh = total vertical deformation [mm]
h = height of Marshall specimen [mm]
σ = vertical stress [N/mm^2]

The experimental creep test results are shown in Table 4. It shows that mixtures with 100% of recycled materials gave the highest creep stain and lowest stiffness. At the same trend, by decreasing the quantity of recycled materials, the creep strain decreased and the stiffness increased.

Table 4 Creep Strain and Stiffness for Different Recycled Materials Concentration.

At constant asphalt Cement in the mix [6 %]		
% age Of Recycled {R} Materials in Mix.	ε {‰}	S [N/mm^2]
100 %	5.23	18.9
75 %	4.88	20.3
50 %	4.83	20.5
25 %	4.73	20.95
0 %	4.54	21.8

INDIRECT TENSILE STRENGTH TEST

The tensile strength of asphalt mixture is a measure of pavement resistance to tensile stresses caused by traffic. For durable asphaltic mixtures, high tensile strength values are required. Also, sufficient stiffness values at high temperatures are needed to avoid excessive permanent deformation or rutting. On the other hand, stiffness values should not be very high at low temperatures to reduce or eliminate crack. The tensile strain at failure is directly related to cracking of the highway pavement. The occurrence of cracking increase as the failure strain decrease[8,9].

In this investigation, the indirect tensile strength for recycled and mixtures of recycled and virgin aggregate will be studied. The following equations were obtained for an approximate samples diameter of 100 mm [10].

$T_s = 2P / \pi d h$ [N / mm ^{2}] (3)

$\varepsilon_p = 6.63\, U/\pi d$ [‰] (4)

Where,

T_s = indirect tensile strength [MPa]
ε_p = strain at failure [‰]
d = diameter of specimen (mm]
h = height of specimen (mm]
U = transverse deformation [mm]

The tensile strength of recycled mixes and mixtures of recycled and virgin materials are shown in Table 5. From this table it can be seen that the recycled mixes at different levels of Virgin aggregate contents have a higher values of tensile strength than that of virgin mixes. Moreover, from the tensile strength results of the recycled mixes it can be noticed that the increase of virgin aggregate content leads to decrease the tensile strength of mixtures. These results can be attributed to the fact that the high tensile strength of the recycled mixes can be explained by the high stiffness of the aged asphalt cement.

Table 5 Indirect tensile strength]MPa] for different percentages of recycled material

Percentage of Asphalt [%]	Percentage of Recycled Materials [%]				
	100	75	50	25	0
5	1.28	1.32	1.30	1.24	1.22
5.5	1.35	1.28	1.32	1.22	1.20
6	1.42	1.34	1.30	1.21	1.27
6.5	1.70	1.64	1.47	1.22	1.30

Table 6 shows the obtained results of strain at failure for recycled and Virgin aggregate mixes at different asphalt content. It can be seen that no trend of strain at failure by increasing the asphalt content in the mixtures of 75% recycled or 25% recycled. In general, mixtures of 100% Recycled materials give a higher strain at failure compared by others mixtures. On the other hand, mixture containing 100% virgin aggregate gives a lower strain at failure value at different asphalt content. Moreover, it can be noticed that decreasing of salvaged aggregate does not significantly effect the strain at failure in the mixtures composed of recycled and virgin materials.

Table 6 Strain at failure [ε_p] for different percentages of recycled material

Percentage of Asphalt [%]	Percentage of Recycled Materials [%]				
	100	75	50	25	0
5	2.64	2.88	2.32	2.41	2.30
5.5	2.74	2.54	2.63	2.58	2.42
6	2.95	2.78	2.68	2.32	2.60
6.5	2.98	2.88	2.96	2.52	2.68

ECONOMIC EVALUATION

Construction estimation is the compilation and analysis of many items that influence and contribute to the cost of the project. A detailed estimate of the cost is prepared by determining the costs of the new materials, construction, recycled pavement, raising of curbs rasing of manhole and others items[11].

Therefore, in this study, costs for construction of 100 m long and 6 m paved width of the road with 2 m side walk width were determined three times. The costs were first calculated based on the traditionally covering road, second using new asphaltic mixtures (100% Virgin materials) after removing the defect asphaltic layer. Third the same road but this time based on using 75% recycled pavement and 25% virgin materials. The difference center around the surface layer of 4 cm thickness. Hence, the economic comparison calculation were made only for this layer because the constructions costs of all other elements in the cross-section will be the same. Unit cost calculations were based on the current prices and rates of equipment used and materials needed. These data were average data obtained for different contractors in Egypt. Table 7 Shows the comparison between the different costs to various cases.

Table 7 Costs analysis for surface course (4 cm) (L.E) using three different cases

Items	Case 1	Case 2	Case 3
C. of crushing 4 cm/m²		4 ± 0.5	4 ± 0.5
C. of hauling to Center-plant/.04 m³			0.4 ± 0.1
C. of hauling to General Rubbish site/0.04 m³		0.6 ± 0.1	
C. of new asphaltic layer, 4 cm Material, Spread and compaction/m²	6 ± 1	6 ± 1	3 ± 0.25
C. of removing and placing of curbs/m	2x4±0.5	-	-
C. of side walk cemented tiles/ m²	15±2	-	-
C. of raising the manhole and Catch basin/ unit	200 ± 20	-	-
Total costs L. E./unit or 1 m	229 ± 23.5	10.6 ± 1.6	7.4 ± 0.85
Total costs L. E.	11000± 1550	6360 ± 1000	4440 ± 500

C. = Cost
Case 1 = covering of Old Asphaltic Pavement Layer
Case 2 = Reconstruction Using new Virgin Materials
Case 3 = Reconstruction Using 75% Recycled and 25% Virgin Materials

For example Case 1,
The total cost= 6x(6x100) + 4x(2x100) + 15x(2x2x100) + 200x3 (3 Manholes @100m) = 11000 L.E.

From the above table it can be concluded that, in case of 75% recycled and 25% virgin aggregate or 100% virgin materials, the total construction operation costs are 4440 ± 500 L.E. and 6360 ± 1000 L.E. respectively. These costs represent almost 40% and 58% of the total cost of covering the old surface course. The higher of covering the old surface course (Case 1) to other cases this due to the high costs of rasing the manhole and side walk cemented tiles. On the other hand, the cost of hauling the old asphaltic layer to general rubbish site and or center-plant not constant but effected by the hauling distances and type of contractor.

CONCLUSIONS

Based on the results of the present study, the following conclusions can be given:-

1. Extracted salvage aggregates has lower percentage of water absorption than virgin aggregate. Percentage water absorption values are 1.0% and 3.2% for salvage and virgin aggregate respectively.
2. Mixtures containing 75% of recycled materials by total weight of mixtures dry aggregates, were required for producing recycled mixes which satisfied the Marshall design criteria. Marshall flow values are within the specification limits (2-5 mm) for all different mixtures of recycled and virgin materials.
3. Test results indicated that mixtures containing 100% Recycled materials gave the highest creep strain and lowest stiffness values compared to other mixtures.
4. The indirect tensile strength values of recycled mixes at different levels of virgin aggregate were higher than those values of pure virgin aggregate mixes.
5. In Case of 75% recycled and 25% virgin aggregate or 100% virgin materials, the total construction operation costs represented about 40% and 58% respectively of the total cost of covering the old surface course.

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