RECYCLING AND REUSE OF OLD ASPHALT COATINGS IN HOT BITUMINOUS MIXTURES

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ABSTRACT

Waste management requires assessment of technological, social, cultural and economic factors jointly. Since the use of industrial wastes in the construction sector allow utilization of wastes in large quantities, it will prevent rapid consumption of limited natural sources, produce economic benefits, and considerably solve the environmental problems caused by wastes. The mineral aggregate amount in asphalt coating mixtures is usually 90-95% in weight, and 75-85% in volume. The mineral aggregate is basically responsible for weight carrying capacity of the coating, and accordingly, the performance of asphalt coating is mainly dependent on the aggregate. ISFALT and TUBITAK MRC have concluded a project about recycling and reuse of old asphalt coatings. According to Marshall mixture ratios; recycled aggregates can be used in bitumen base, binder and wear layer with the ratios of 30%, 20% and 10% respectively. Resulting recycled asphalt coating was applied on the road first time in TURKEY by ISFALT.

Keywords: waste, recycle, reuse, recycled asphalt pavement, hot mix asphalt

1. INTRODUCTION

The design of Highway Structures shall generally be in accordance with the design manual for roads. The structure of a road is constructed in two main layers in terms of its function, properties, and sequence of construction. The main function of bottom layers is to transfer the loads induced by the top layer to a larger surface area, and to protect the road from deformations. The upper layer of highways is made of sub-base, base, and pavement layers. The upper layer reduces the loads induced by traffic, protects the bottom layer and is constructed over the bottom layer in order to provide a smooth rolling. This layer is exposed to static and dynamic loads with the weather and traffic effects. Therefore, reinforcement of asphalt is needed to prevent deformation in asphalt layer due to the traffic load, climate and environmental conditions every 5 years.

According to recent data, approximately 3 million tons per year hot bituminous mixture is laid in Istanbul. New asphalt pavement over existing wearing course on Istanbul streets reduces the road safety in consequence of loss of curb height and accordingly creates a need for manhole adjustment. But the diminishing availability of natural aggregates around Istanbul created a new demand for new aggregate resources. In recent years, the use of old pavement has become a main topic due to the above mentioned geometrical factors, economic and environmental reasons. It is intended to provide energy and cost savings with the reuse of old pavement.

Recycled asphalt is produced from old asphalt pavement by various processes [1]. During the production of recycled asphalt from reclaiming asphalt pavement, the most important factors in the mix design are the aggregate percentage, binder type and preparation of mix The studies on the recycling of old asphalt pavements have started more than 20-30 years ago in the world. According to the reports of the regional road authorities in the U.S., the recycling rate is roughly 80% in some areas. Reclaimed asphalt is one of the most valuable materials to use in asphalt production, and need to be tested according to the laws and regulations of the country [2].

In case of Turkey, the studies in reusing of old asphalt pavement have been started in 1996, but mostly they had been used as a sub-base, filling material or sent to landfill areas [3-4-5]. In both cases, the environmental and visual pollution were created. Collected materials in factories were sold for a cheap price; otherwise they were kept at the factory site. Nowadays, local authorities have difficulties to locate new landfills in Istanbul (Turkey). Consequently, ISFALT Inc (Asphalt Company) decided to start a new project entitled “Recycling and Reuse of Old Asphalt Pavements in Hot Mix Asphalt”. ISFALT Inc. initiated and carried out this R&D project in partnership with the Materials Institute of TUBITAK Marmara Research Centre (TUBITAK MRC), and the project was supported by TUBITAK TEYDEB (The Scientific and Technological Research Council of Turkey – Technology and Innovation Funding Programs Directorate). The project results were put into practice in the ISFALT plants. This paper presents R&D studies, pilot study and implementation of that project with the results of performance test.

2. MATERIALS AND METHODS

In this project, recycled asphalt with old asphalt pavement in accordance with the standards and specifications was selected as primary output. To achieve the desired output, work steps were carried out as described in Figure 1.

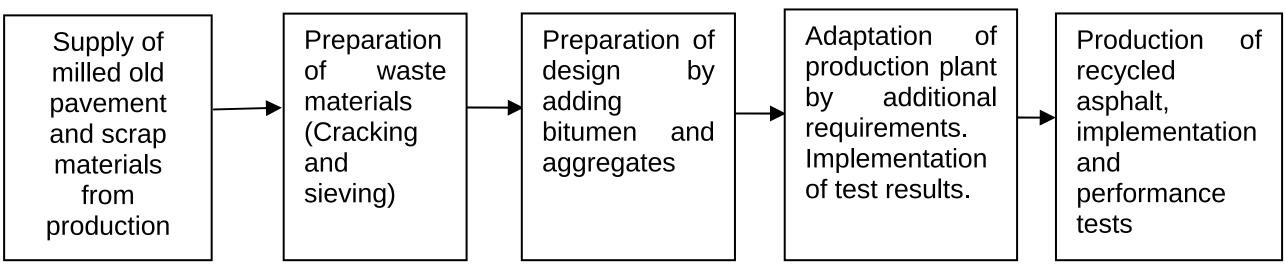


Figure 1 - Process of recycled asphalt production

2.1. Development of recycled asphalt mixture in the laboratory

Firstly, milled old pavement and slab waste asphalt were brought to standard sizes that can be used in hot mix asphalt by cracking and sieving methods. After cracking, reclaimed asphalt pavement was stored in such a manner that the height of dump does not exceed 2-3 m. A representative sample of reclaimed asphalt was taken and its gradation was tested according to TS 130 (Turkish Standard). (Table 1)

Table 1 - Sieve analysis for reclaimed pavement (Gradation)

Sieve Size	Inch	3/4"	1/2"	3/8"	No:4	No:10	No:40	No:80	No:200
	mm	19, 0	12, 5	9, 5	4, 75	2, 00	0, 420	0, 180	0, 075
Passing	%	100	90,0	84,2	64,4	40,2	18,3	12,4	9,0

Asphalt pavement consists of bituminous binder and mineral aggregate mixed together. Coarse and fine aggregates were obtained from Cebeci region in Turkey. The properties of aggregates and bitumen were given in a paper entitled “Effects of Recyled Waste Tires in Hot Bituminous Mixture” presented by the same authors at this conference. The chemical analysis of bitumen of reclaimed asphalt pavement and 50/70 bitumen used in this study were performed with Elementar GmbH vario MICRO CHNS analyzer and results of analysis were shown in Table 2. As seen from the table, the composition of bitumen in recycled asphalt was similar to TUPRAS (Turkish Comp.) 50/70 bitumen, although bitumen sample obtained from recycled asphalt was the used one.

Table 2 - Chemical composition of bitumen samples

Element	Bulk Density (%)	
	50/70 Bitumen	Recycled Bitumen
Carbon	84,71	81,27
Hydrogen	9,663	9,417
Sulphur	3,390	3,497
Oxygen	-	-
Nitrogen	0,54	0,54

An asphalt pavement structure consists of three layers. The upper layer of structure is the wearing course. The main function of upper layer is to distribute the load of traffic to the lower levels. The binder course is in between the wearing course and the base course. It helps to transmit the stress through the base course. The base course is the bottom layer and the max. size of aggregate is 1½" (37,50 mm) in this level. The use of coarse aggregate in this layer provides a structure with voids, and this layer with voids protects the upper level from the ground forces [6-7]. Table 3 presents the ratios of conventional and recycled asphalt mix designs produced according to Marshall Method of Turkish Highways Specification. The specific gravities of aggregate and bitumen are given in Table 4, the gradation of aggregates are shown in Table 5.

Table 3 - Ratios of conventional asphalt and recycled asphalt mix according to Marshall method

Method: Marshall	Ratios of Conventional Asphalt Design (%)			Ratios of Recycled Asphalt Design (%)		
	Wearing Course Type 1	Binder Course	Base Course	Wearing Course Type 1	Binder Base	Bituminous Base
No 4 Aggregate	-	-	30	-	-	30
No 3 Aggregate	-	20	-	-	20	
No 2 Aggregate	10	20	15	10	20	10
No 1 Aggregate	45	20	20	40	15	15
Fine Aggregate	45	40	35	40	25	15
Milled Asphalt				10	20	30

Table 4 - Specific gravity of aggregates and bitumen used in design

Specific Gravity of Coarse Aggregates (gr/cm^3)	2,684
Specific Gravity of Fine Aggregate (gr/cm^3)	2,629
Specific Gravity of Filler (gr/cm^3)	2,776
Specific Gravity of Bitumen (gr/cm^3)	1,023

The results of tests carried out on conventional asphalt and recycled asphalt, and the values of Technical Specifications of Turkish Highways were presented in Table 6. As seen in table, results of mix design are suitable for the specifications.

Table 5 - Gradations of aggregates used in designs

Sieve No		Cumulative (%) Passing					
inch	mm	No 4 Aggregate	No 3 Aggregate	No 2 Aggregate	No 1 Aggregate	Fine Aggregate	Milled Asphalt
1½"	37,5	100,0	100,0	100,0	100,0	100,0	100,0
1"	25,0	60,2	100,0	100,0	100,0	100,0	100,0
3/4"	19,0	26,5	47,3	93,9	100,0	100,0	100,0
1/2"	12,5	5,8	10,7	21,3	99,1	100,0	90,0
3/8"	9,5	3,5	5,8	5,9	72,7	100,0	84,2
No: 4	4,75	2,5	2,2	3,1	14,5	96,9	64,4
No: 10	2,00	1,8	2,0	2,7	2,6	62,6	40,2
No: 40	0,425	0,9	1,8	2,3	2,0	27,4	18,3
No: 80	0,180	0,5	1,7	2,1	1,8	18,5	12,4
No: 200	0,075	0,3	1,5	1,9	1,6	12,5	9,0

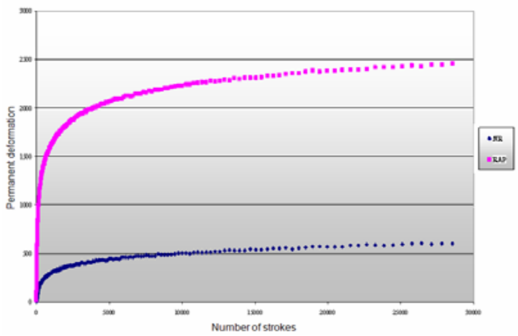
Table 6 - Results of asphalt designs

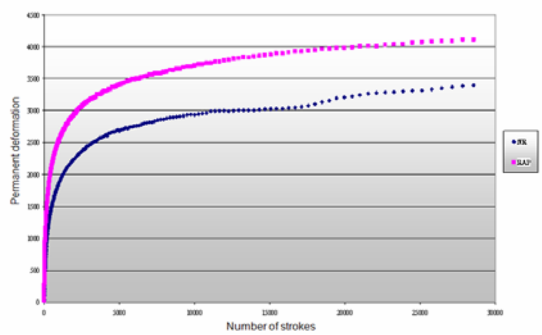
Properties	Design Results						Specification Values
	Conventional Asphalt			Recycled Asphalt			
	Wearing Course Type 1	Binder Course	Base Course	Wearing Course Type 1	Binder Course	Base Course	A: Wearing B:Binder BT: Base
Optimum Bitumen Content %	4,80± 0,3	4,25± 0,3	3,50± 0,3	4,85± 0,3	4,25± 0,3	3,65± 0,3	A:4,0 – 7,0 B: 3,5 – 6,5 BT: 3,0 – 5,5
Unit Weight (gr/cm^3)	2,410	2,417	2,431	2,404	2,412	2,422	-
Air Voids %	4,10	4,60	5,00	4,00	4,70	5,20	A:3 - 5 B:4-6 BT: 4 – 7
Voids filled with Asphalt (VFA) %	70,00	66,00	59,00	70,00	65,00	59,00	A:65 - 75 B:60-75 BT: 55 – 70
Stability (kg)	1490	1210	1180	1560	1120	1200	A:Min. 900 B: Min. 750 BT: Min. 600
Flow (mm)	2,65	3,30	3,60	2,80	3,15	2,90	A:2 - 4 B:2-4 BT: 2 - 5
Voids of Mineral Aggregates % (VMA)	13,80	13,20	12,10	14,00	13,50	12,50	A:Min. 14 B: Min. 13 BT: Min. 12
Effective Specific Gravity of Aggregates (gr/cm^3)	2,697	2,699	2,699	2,697	2,699	2,700	-
Theoretical Max Specific Gravity	2,509	2,530	2,558	2,508	2,530	2,552	-

2.2. Asphalt performance test for recycled asphalt produced in the laboratory

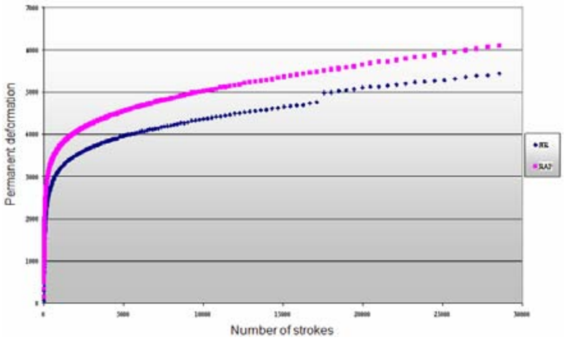
The dynamic creep test for the samples of conventional and recycled asphalt which are prepared in the laboratory were accomplished to determine the permanent deformation. The static creep test and indirect tensile strength test were performed to find out the creep modulus and elastic modulus, respectively.

The creep modulus test was performed on the reclaimed asphalt pavement (RAP) at 5, 25, and 40ºC .The shape of the load curve is plotted as shown in Figure 2. Also, the deformation was measured by applying a constant axial load to the test specimens for 3600 sec at 5, 25, 40ºC.



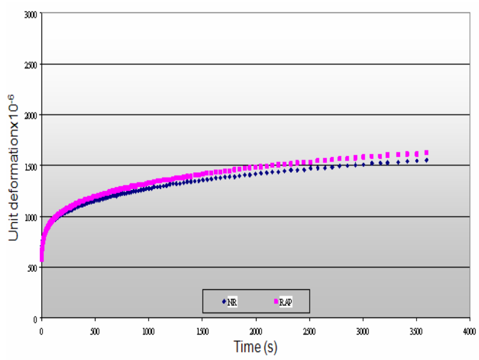


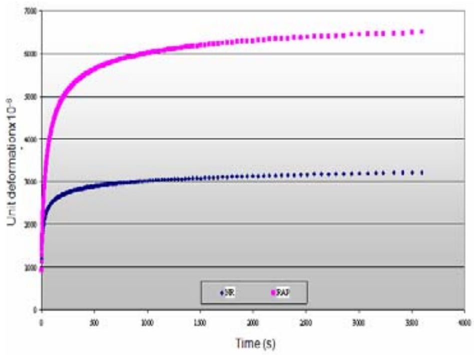
a. 5ºC b. 25ºC



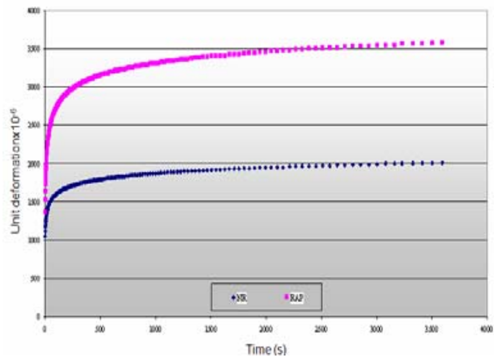
c. 40ºC

Figure 2 - Distribution of permanent deformation (Repeated creep, a.5ºC, b.25ºC, c.40ºC) of conventional asphalt and recycled asphalt depending on the number of strokes.





a. 5ºC b. 25ºC



c. 40ºC

Figure 3 - Distribution of creep deformation (Static creep, a.5ºC, b.25ºC, c.40ºC) of conventional asphalt and recycled asphalt depending on time

To provide an input to pavement design, evaluation and analysis, the indirect tensile test were performed at 5, 25, and 40ºC. This study aimed to investigate the effects of temperature, loading amount and loading time on elastic modulus. The load was applied to the specimens for 1000, 2000, and 3000 msec. Three readings were taken at 40, 60, and 80 msec loading speed for each load time. It was found that there is no big difference between conventional asphalt and recycled asphalt considering the data obtained at 2000 msec with 60 msec of load speed. It was observed that the mixtures have a high stiffness of rigid at lower temperatures and at 25ºC.

The indirect tensile strength test was conducted to determine the properties of recycled asphalt and conventional asphalt. Indirect tensile strength characterizes the tensile stress of bituminous mixture through temperature and fatigue. The value of indirect tensile strength and deformation obtained from these tests are used to determine the optimum bitumen content of mixture and the potential formation of fatigue cracks in bituminous mix. A cylindrical specimen was loaded through its diametrical axis and the loading was applied until it causes a tensile deformation at 25ºC and 40ºC. The indirect tensile strength of conventional asphalt and recycled asphalt were shown in Figure 4.

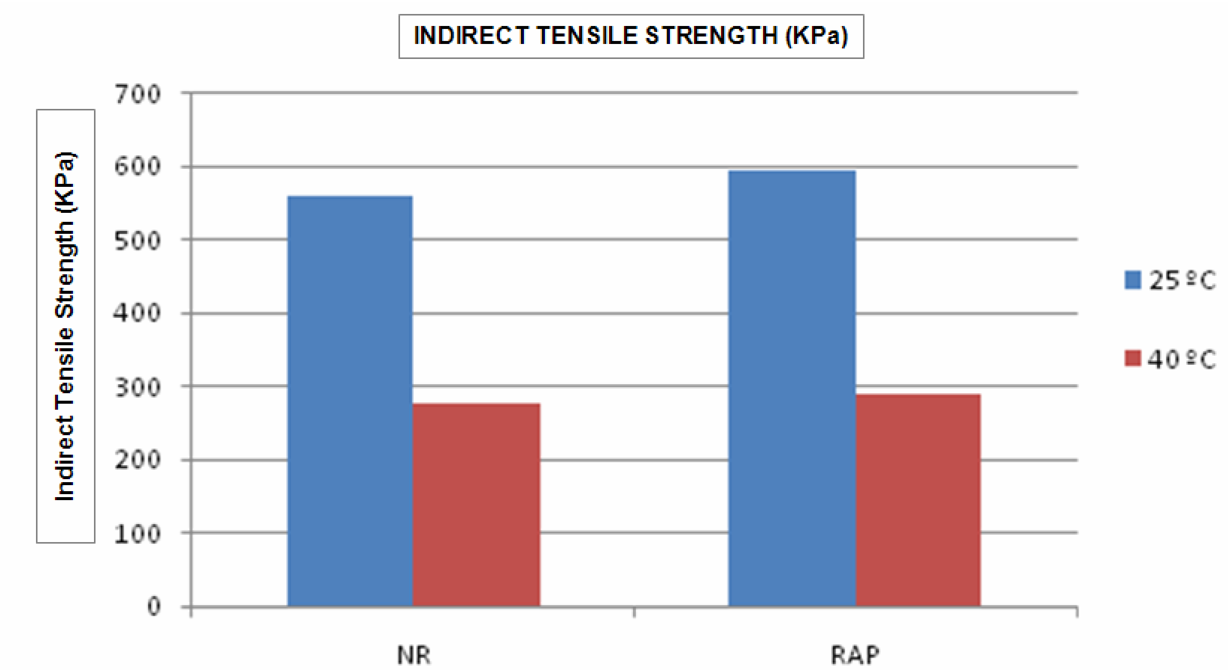


Figure 4 - Indirect tensile strength of conventional asphalt (NR) and recycled asphalt at different temperatures

2.3. Pilot production of recycled asphalt by implementation of laboratory results

After achieving high performance results for recycled asphalt manufactured in the laboratory, a pilot study was initiated at the Habibler Asphalt Plant of ISFALT Inc (Turkey). The wheel tracking test was performed on samples from produced asphalt to find out the bitumen content and gradation. Bitumen content was determined by extraction method with Asphalt Analyzer. Test results are given in Table 8. According to the test results, the bitumen content and gradation are found suitable for the design defined by ISFALT laboratory.

Table 8 - The Bitumen content of wearing course type 1 with recycled asphalt

Asphalt type	Bitumen content (%)
Conventional Wearing Course Type1	4,85 ±0,3[2]
Recycled Asphalt Wearing Type 1	4,77

2.4. Application of recycled asphalt and performance tests on the road

The recycled asphalt and conventional asphalt produced during the pilot study were applied on two-lane road in Bagcilar, Istanbul. Cylindrical samples were taken from the completed layer, the compaction ratio test and wheel tracking test were carried out. The aim of the compaction ratio test of asphalt is to determine compaction ratios of asphalt which is produced, laid and compacted. The compaction ratios of specimens cut from road are given in Table 9 and they are found suitable with Highways Specification of Turkey [8].

Table 9 - Core test results

Sample	Compaction Ratio (%)	Specification (%)
Recycled Asphalt wearing course Type 1 (1)	98,6	
Recycled Asphalt wearing course Type 1 (2)	99,8	Min. 98
Average	99,2	

Wheel Tracking Test is one of the most important tests to assess the performance of asphalt mixtures. Permanent vertical deformation along the road surface in contact with the wheel of vehicles is defined as Wheel Track (Rut). The wheel track problem with the increasing number of vehicles, the increase in axle weight, changes in axle systems, and the increase in internal pressure of tires is needed to be solved. It affects both safety and comfort on roads. It is more difficult to control of steering during changing lanes on a rutted road. In rainy conditions, the water on the wheel track causes icing, and increases the break time. The resistance of deformation of bituminous mix is evaluated by measuring the depth of rut formed with the repeated wheel loading (70kg) to the pavement samples at a constant temperature. This test method is applicable to mixtures with upper sieve size less than or equal to 32mm and provides the mean wheel-tracking slope (WTS Air mm/1000rpm), mean proportional rut depth (PRD Air %) and mean rut depth (RD Air mm). ISFALT Inc.'s Hamburg Wheel Tracking device measures at 60ºC and 20000 wheel passes.

As the last step of the study, after one month of using this road, cylindrical samples were taken from the completed layer by using a 20 cm blade according to TS EN 12697-22 and the wheel tracking test was performed. The results of tests on samples manufactured in the laboratory, taken from production plant and cut from road were given in Table 10 comparatively.

Table 10 - Comparison of experimental results of wheel tracking

Asphalt type	Depth of rut in sample produced in the laboratory (mm)	Depth of rut in sample obtained from production (mm)	Depth of rut in sample obtained from existing road (mm)
Conventional Asphalt	3,51	-	3,88
Recycled Asphalt	2,70	2,32	3,20

3. RESULTS AND EVALUATION

In this study, the physical and chemical characterizations of reclaimed asphalt material were performed after cracking and sieving. Bitumen content was defined and the gradation of aggregates was determined through the physical and chemical analysis of bitumen. Afterwards Marshall mix design was done. According to the results of the analysis of original bitumen (original bitumen + recycled bitumen), specimens were produced in laboratory experiments and the asphalt performance tests were applied to this specimens.

Recycled asphalt was produced with appropriate design and then applied to the road. Conventional Asphalt and Recycled Asphalt were compared in terms of performance. According to Marshall mixture ratios; recycled aggregates can be used in bitumen base, binder and wear layer with the ratios of 30%, 20% and 10% respectively.

In repeated creep test, a constant axial load with 250 KPa was applied to the test specimens for 1000msec (500msec load and 500msec unload) for 8 h at 5, 25, and 40ºC. The permanent deformation of samples was defined at the end of each loading cycle. It is found that permanent deformation of recycled asphalt in a cold climate is five times more than conventional asphalt and this difference decreases as the temperature increases. Thus, permanent deformation of recycled asphalt is about 1.5 times more than conventional one at 25ºC and 40ºC.

Static creep tests were carried out for the samples produced in the laboratory to identify the creep stiffness of dense-graded hot mix under rotational and uniaxial load. The stiffness of asphalt cement mix was estimated by calculating wheel rut and potential of cracking at low temperature, with the results obtained from these tests. According to test results; a significant difference was not observed between conventional asphalt and recycled (RAP) asphalt, however changes in unit deformation was observed as the temperature increases. It is found that higher deformation was occurred on RAP at 25 and 40ºC.

Indirect tensile strength characterizes the tensile stress of bituminous mixture through temperature and fatigue. To determine the indirect tensile strength of conventional asphalt and recycled asphalt, indirect tensile strength tests were implemented at 25ºC and 40ºC. Studies indicated that the indirect tensile strength values of recycled asphalt were slightly higher than the conventional one but the difference can be ignored.

In comparison the results of wheel track test, the results of recycled asphalt were found to be better than conventional asphalt at any condition. It is concluded that an average value is required to examine the findings using different samples of core taken from the road.

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