EFFECTS OF RECYLED WASTE TIRES IN HOT BITUMINOUS MIXTURES

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ABSTRACT

With enforcement of laws and regulations regarding wastes in the world, continuous waste management has become a legal requirement. The tendency is acceleration of recycling, rendering waste management continuous with collaboration of people, private and public sector and finding reusability areas for waste materials. Tires are generally made of rubber and steel fibers, and contain products that can be recycled up to ~95%. The restrictions regarding storing of used tires were put into effect with the directives since 2003 and recycling thereof has been required. In this presentation; application of recyclable waste tires in hot asphalt mixtures is determined. Performance of conventional asphalt mixtures and asphalts prepared with recycled waste tires is compared. Recycled asphalt is fabricated with the specified formula, which is laid onto the road during production. The project results are put into practice in the ISFALT plants of Turkey.

Keywords: asphalt, recycle, recycled asphalt, waste, waste tires

1. INTRODUCTION

In accordance with the Landfill Regulations, whole used tires cannot be deposited at landfill. Legal limitation and liabilities, inspections and precautions to be made, legal and criminal liabilities concerning the collection of waste tires, its transportation, temporary storage, recovery, disposal, import and transit pass are specified at "The Control of Waste Tires Regulations, in Turkey since 2006 [1].

After these regulations, there is a need to find alternative uses for post –consumer tires in the world and in Turkey. Civil engineering is the area where a number of uses are possible for used tires. Tires can be used in a number of forms, as whole tires, tire bales or processed into shred, chips or granulate [2-3].

Hot mix asphalt (HMA) is a homogeneous mixture of suitable aggregate coated with the asphalt cement. Asphalt and aggregates are combined in an asphalt mixing plant where all the components of materials are heated, proportioned and mixed to produce the desired paving mixture. When the mixing time is complete, the hot mix is then transported to the paving site and spread in a partially compacted layer to a uniform, even surface with a paving machine (finisher). While the mixture is still hot, the paving mixture is compacted by heavy rolling machines to produce a smooth pavement surface.

The diminishing availability of natural aggregates used in asphalt production all over the world has forced asphalt manufacturers to seek out alternative resources. By the recycling of old asphalt pavements in Turkey; interest has focused increasingly on waste materials which can be used as aggregates. Especially the amount of used tires has attracted the attention among them.

According to the literature, the behavior of modified bituminous asphalt using a rubber powder has been studied by R.Kettab and A.Bali. In this study, granulated rubber with a density of 0,8 g/cm^3 and maximum size of 2mm has been used. Voids are filled by using rubber, compression and mechanical strength were increased [4].

On the other hand; the results from Project of Florida Department of Transportation indicate that, there are two ways to use granulated rubber in hot mix asphalt. The wet process; called asphalt- rubber in which 18-26% (by weight of asphalt cement) tire rubber is reacted with asphalt at elevated temperatures (375-425 ^{o}F) for one to two hours to produce a material suitable for use as a binder in HMA construction. The dry process; called rubber-modified mixes, in which rubber amounting to about 3 to 5% of the aggregate weight is added to the aggregate before the asphalt is introduced and mixing occurs. Principal differences between these two processes are that the dry process rubber is much coarser than wet process rubber, and the dry process uses 2 to 4 times as much as the wet process, and function of rubber in process [5-6].

This paper contains some of the results of the project named as “Recycling of Waste Tires in Bituminous Hot Mixture, Pilot Production and Implementation” performed by ISFALT Inc. and TUBITAK MRC. Project is supported by TUBITAK (The Scientific and Technological Research Council of Turkey) TEYDEB (Technology and Innovation Funding Programs Directorate).

2. MATERIALS AND METHODS

2.1. Determination of properties of granulated car tire

In this study, waste automobile tires were selected to use in bituminous hot mix. The gradations of waste tires were carried out in the Cetinkaya Inc. (Ankara-Turkey). During the granulation process, steel particles were removed magnetically and used automobile tires were ground into smaller particles at different crushers. The remaining part was processed in a third crusher and textile particles were removed before packaging.

Granulated rubber wet analysis was completed according to ASTM-D297-93(2006), results are given Table 1. The mineralogical analysis of inorganic materials (9% of total granulated rubber) was performed by SHIMADZU XRD-6000 with Cu X-Ray Tube (λ=1.5405 Angstrom). Phases are presented in Table 2.

Table 1- Chemical analysis of granular tire

Chemical Analysis	Weight %
Softener	11,2
Rubber	48,6
Type of rubber	SBR/ Natural Rubber
Carbon Black	30,7
Inorganic Filler	9,00
Moisture	0,5

Table 2- Qualitative mineralogical analysis of inorganic part of granulated rubber

Inorganic phases	Powder Diffraction File Number (PDF)
Zinc oxide; ZnO	PDF No: 36-1451
Anhydrite;$CaSO_4$	PDF No: 37-1496
Silica,SiO_2	PDF No: 46-1045
Calcite,$CaCO_3$	PDF No: 5-586
Fayalite,$(Fe,Mg)_2SiO_4$	PDF No: 31-633
Magnetite,Fe_3O_4	PDF No: 19-629

Scanning electronic microscope (SEM) was used to characterize the microstructures of granulated rubber. As seen in Fig.1, the observed grain size (0-0,5mm) is similar in general. The sieve analysis of granulated rubber was performed according to Turkish Standard (TSE 130). The results are shown in Table 3.

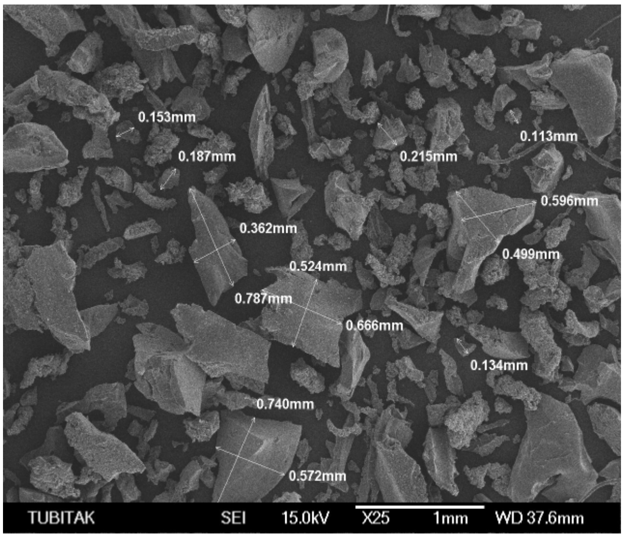

Figure 1- SEM image of granulated rubber

Table 3- Sieve analysis of granulated rubber sample (%)

Sieve No		Cumulative weight (g)	Cumulative	
Inch	mm		Retained on sieve (%)	Passing (%)
No: 10	2,00			100,0
No: 40	0,425	210,5	70,9	29,1
No: 80	0,180	284,5	95,8	4,2
No: 200	0,075	295,4	99,4	0,6
		Sample Weight	297,1 g	

2.2. Determination of properties of aggregates and bitumen to be used in hot mixture

Asphalt pavement is a mixture of fine and coarse aggregate, mineral filler and stone dust with bituminous binder. Aggregates used in this study were tested as stated in Highways Technical Specifications General Directorate of Highways, The Ministry of Public Works and Settlement, Republic of Turkey [7]. Results are given in Table 4. The results of tests indicate that aggregates and stone dust are suitable to use in HMA.

The properties of 50/70 bitumen which is produced in Habibler Plant of ISFALT Inc. are shown in Table 5. The chemical analysis of bitumen is presented in another paper which is named as “Recycling and Reuse of Old Asphalt Coatings in Hot Mixtures”, and presented at this congress. The results of bitumen tests were compliant with the specification.

Table 4- Results of aggregate tests and comparisons to specifications

Properties	Base	Binder Base	Wearing course	
	Specification Limits	Specification Limits	Results	Specification Limits
Abrasion Loss (%) (TS EN 1097-2)	Max. 35	Max. 35	21,5	Max. 30
Soundness Test (%) (ASTM C 88)	Max. 12	Max. 12	0,83	Max. 10
Flatness index (%) (BS-812)	Max. 35	Max. 35	26,5- 26,9	Max. 30
Water Absorption (%) (TS EN 1097-6, ASTM C 127)	Max. 2,5	Max. 2,5	0,32	Max. 2,0
Resistance to water action-peeling (%)(Nicholson Method)	Min. 50	Min. 50	60- 70	Min. 50

2.3. Marshall Mix design for asphalt with granulated tire

Marshall Design Method (Turkish Standard-TS 3720) is used to determine the optimum bitumen content of aggregates mixtures which is prepared with desired gradation. Marshall designs were performed by adding 1%, 1.5% and 2% granulated rubber by weight of the total mix to the bituminous hot mixture in accordance with Specification of Highways Wearing Course (Type 1) [7]. Test results and specification data are given comparatively in Table 6. As seen in Table 6, by adding 2% granulated rubber to hot asphalt mixture, optimum bitumen content (%) and flow value (mm) were increased, the stability value (kg) was decreased. Therefore, the optimum ratio of waste tires to use in hot bituminous mixture was accepted as 1% and 1.5%.

Table 5- Bitumen tests and comparisons to specifications.

Test	Unit	Test Results Specifications	 50 - 70 Bitumen
Penetration (TS EN 1426)	0,1 mm	50 - 70	58,0
Softening Point (TS EN 1427)	°C	46 - 54	49,3
RTFOT (163°C, 5 h) (TS EN 12607-2)			
• Changes in mass	%	Max. 0,5	0,10
• Needle penetration	%	Min. 50	75,5
• Softening Point	°C	Min. 48	52,5
• Softening point increment	°C	Max. 9	3,2
Flash Point (TS EN ISO 2592)	°C	Min. 230	310,0
Others			
Ductility (TS EN 13589)	mm	-	+101,5
Specific Gravity (TS 1087)	gr/cm^3	-	1,020
Elastic Recovery (TS EN 13398)	%	-	0,0

2.4. Performance tests on rubberized asphalt developed in the laboratory

The indirect tensile strength test was conducted to determine tensile strength and tensile stress. Marshall Stability test was performed to determine stability of asphalt mixture [8]. A cylindrical specimen was loaded through its diametrical axis and the loading was applied until it causes a tensile deformation at 25°C and 40°C. The measured tensile strength for Traditional (NR) and Rubberized Asphalt (LAS) are given in Fig.2. As seen in this figure, tensile strength of rubberized asphalt is less than the tensile strength of traditional asphalt.

Table 6- Results of asphalt designs according to specification

Properties	1% wt.	1,5% wt.	2% wt.	Specification Values
Optimum Bitumen Content %	5,40± 0,3	5,80± 0,3	6,70± 0,3	4,0 – 7,0
Penetration	61 (50- 70)	61 (50- 70)	61 (50- 70)	-
Unit weight (gr/cm^3)	2,382	2,364	2,330	-
Voids%	4,20	4,40	4,60	3 - 5
Voids Filled with Binder %	72,00	72,00	73,00	65 - 75
Stability (kg)	1280	1100	960	Min. 900
Flow (mm)	3,50	3,60	4,80	2 - 4
Voids of Mineral Aggregates % (VMA)	15,20	16,10	18,00	Min. 14
Coarse Aggregate Specific Gravity (gr/cm^3)	2,684	2,684	2,684	-
Fine Aggregate Specific Gravity (gr/cm^3)	2,629	2,629	2,629	-
Specific Gravity of Filler (gr/cm^3)	2,776	2,776	2,776	-
Effective Specific Gravity of Aggregates (gr/cm^3)	2,697	2,697	2,697	-
Specific Gravity of Bitumen (gr/cm^3)	1,023	1,023	1,023	-
Theoretical Max Specific Gravity	2,489	2,475	2,446	-
Number of Blow	75	75	75	75
Compaction Temperature (°C)	135	135	135	-

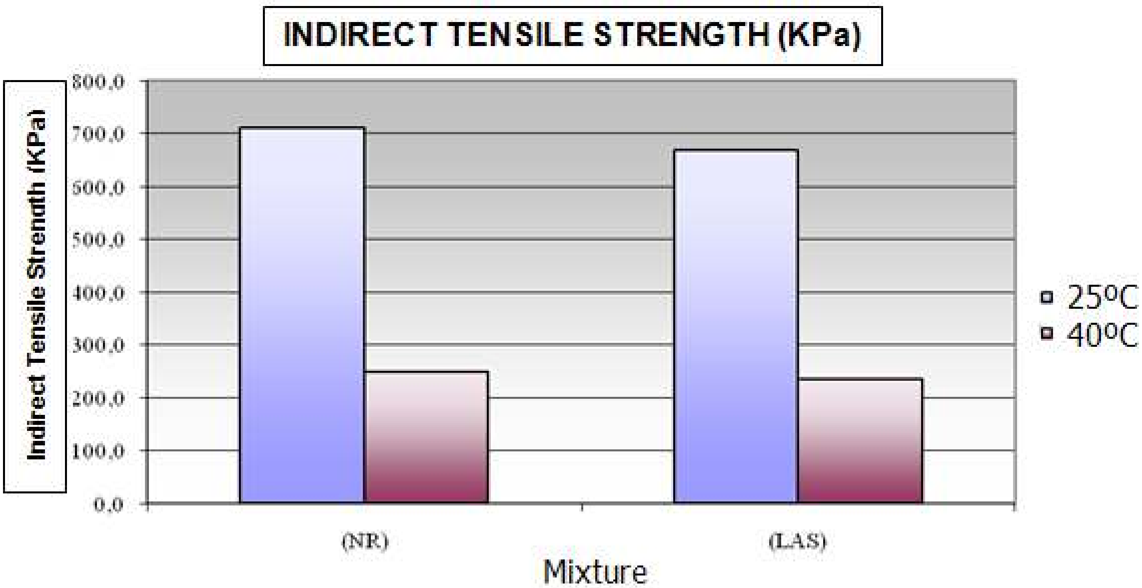

Figure 2- Indirect tensile strength of traditional asphalt and rubberized asphalt

2.5. Production of rubberized asphalt and paving

To assess to the feasibility of experiments performed in the laboratory, a pilot production was conducted at the Habibler Plant of ISFALT Inc. by the project team. In this pilot production, after completing the packaging process of rubber crumb, a bitumen content and gradation test were carried out to compare traditional asphalt type 1 and rubberized asphalt samples. Bitumen content was determined by extraction method with Asphalt Analyser. Test results are given in Table 7. According to the results, the bitumen content and gradation were found similar to the design defined by laboratory.

Table 7- Bitumen content of rubberized wearing asphalt Type 1

Asphalt type	Bitumen Content (%)
Traditional Wearing Type 1	5,40 ±0,3
Rubberized Asphalt 1	5,27

The rubberized asphalt and traditional asphalt produced during the pilot study were laid on the two-lane road in Istanbul (Turkey). After one month of using this road with moderate traffic conditions, cylindrical samples were taken from the completed layer by using a 20 cm blade. The compaction test and wheel tracking test were performed. The results of core test were shown in Table 8. According to the results the percentage of compaction were found suitable with the highways specifications.

Table 8- Core test results

Sample	Compaction (%)	Specification (%)
Rubberized Wearing Type 1	97,9	Min. 98
Rubberized Wearing Type 1	98,4	
Average	98,2	

Permanent vertical deformation along the road surface in contact with the wheel of vehicles is defined as Wheel Track. External factors such as load, internal pressure of tire, temperature and climatic conditions, and internal factors such as the effect of the bituminous binders and aggregate can cause wheel track problems. 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. Therefore, measuring the rut depth is needed to evaluate the performance hot bituminous mixtures. The results of tests on samples produced in the laboratory, taken from production plant and cut from road were given in Table 9 comparatively.

Table 9- Comparison of wheel tracking test results

Asphalt Type	Samples prepared in the laboratory (mm)	Samples taken from production plant (mm)	Samples cut from existing road (mm)
Traditional Asphalt	3,51	-	3,88
Rubberized Asphalt	2,58	2,11	2,06

3. RESULTS AND DISCUSSIONS

The physical and chemical characterizations of waste tires were performed by granulation and sieving. Bitumen content was defined and the gradations of aggregates were determined through the physical and chemical analysis of bitumen. Afterwards Marshall mix design was done. According to the results of the analysis of bitumen, specimens were produced in the laboratory and the asphalt performance tests were applied to the specimens. Traditional Asphalt and Rubberized Asphalt were compared in terms of performance. Rubberized asphalt were manufactured with appropriate design in the plant and then applied to the road.

The percent of fine material in the asphalt mixture increased with granulated waste tire addition. Although the added amount of rubber tire is as %1, %1,5 and %2, volume of granulated waste tire is nearly 4 times larger than the volume of aggregate. Because of this; the surface area of the material which is coated with bitumen and optimum bitumen content increased. On the other hand; the flow value increased with bitumen content.

According to Turkish Highway Technical Specifications, in wearing course asphalt layer air voids content must be between %3 - %5. Air voids content of the mix designs produced for this study is within the limits of specifications.
Since granulated waste tire is lighter than aggregates, the bulk density of asphalt specimens decreases with increasing in rubber tire content.
As known, the percent of air voids in asphalt specimen is calculated as follows;

$$Vh = \frac{D_T - D_P}{D_T} * 100$$

Vh : Air voids percent
DT : Maximum density
D_P : Bulk density

The percent of air voids increased by the decreasing in the bulk density of asphalt mixture as can be seen from the formula.

Rubber kind materials have lower strength compared to aggregates and deforms significantly under a specific load. As a consequence the stability of asphalt decreases with an increase in granulated waste tire content in the asphalt mixture.
Indirect tensile strength characterizes the tensile stress of bituminous mixture through temperature and fatigue. To determine the indirect tensile strength of traditional asphalt and rubberized asphalt, indirect tensile strength tests were implemented at 25°C and 40°C. Studies indicated that the indirect tensile strength values of rubberized asphalts are slightly

less than the traditional one, but the difference can be ignored. The results of wheel track test of rubberized asphalt were better than traditional asphalt at any condition. The rubberized asphalt and traditional asphalt produced during the pilot study were laid on the two-lane road in Istanbul on 21.10.2009. There is no significant defect or problem on the performance or serviceability of the road since then. Studies carried out for the use of waste tires in hot mix asphalt has become the first application in Turkey.

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