GLOBAL RESEARCH NETWORK

AMERICAN Journal of Engineering, Mechanics and Architecture
Volume 4, Issue 02, 2026 ISSN (E): 2993-2637

Using Recycled Tyre Rubber in Road Paving Mixtures

Sarah Safaaldeen Musaa, Noorance Al-Mukarama, Hayder Kamil Shanbaraa*
Al-Muthanna University, College of Engineering, Department of Civil Engineering, Samawah, Iraq

Abstract: This investigation presents experimental works of using Recycled Tyre Rubber (RTR) in asphalt mixture using dry mixing method. Two types of asphalt mixtures were designed and produced for preparing surface layer. One of them includes well-graded natural aggregate with crumb rubberized binder. Whereas the second mixture implemented by adding specific amounts of RTR as a replacement material of 50% of fine aggregated retaining on sieve No. 50 (0.3 mm). Following that, both prepared mixtures were tested in Marshall apparatus to investigate their volumetric properties. Then, the results of Marshall were compared with the Iraqi general specifications for roads and bridges SORB/R9. The findings showed significant increases in the values of Marshall stability and flow. In addition, contents of voids achieved the acceptable requirements of SORB/R9 in the modified mixtures. Finally, the addition of rubber particles as a past of asphalt mixture contents is a technical process that shows significant improvement of its life, reduces cracking and wear and enhances adhesion and anti-slip properties.

Keywords: Asphalt mixture, Tyre rubber, Crumb rubber, Dry mixing method, Marshall tests.

1. Introduction

Applying Recycled Tyre Rubber (RTR) in flexible pavement roads is an essential issue to enhance road infrastructure as well as achieve economic budget and long-term life for roads. Even though flexible pavement roads pose heavy traffic loads under prevalent and extreme weather conditions, deformations such as patches, rutting and crackings will appear and remedy processes are needed.

Since the issue of sustainability has been highlighted, it is necessary to investigate alternative solutions for improving road infrastructure. Therefore, recycling tyre rubber is commonly utilized in asphalt mixtures. Nowadays, waste tyres are extensively used in road paving mixtures not only due to their cheap values but also to reduce their environmental hazards such as non-biodegradable nature as well as their potential to cause landfill overflow. Many studies have been carried out addressing using of specific amount of RTR as a replacement for aggregates. This alternative might improve mixture performance, its durability as well as minimize formation of cracks and water damage. Based on previous works [1], [2], [3], [4], [5] adding a certain amount of RTR as a replacement of some aggregates (from 1 to 3% by weight) using dry process might help to decrease the environmental impacts of pollution and results in good performance roads [6].

On the other hand, mixing time and temperature conditions are the major factors that might affect the cohesion between the CR and other mixture components. This limitation has been established in the few decades by improving the interaction between rubber granules and asphalt mixture [7]. Moreover, further assessment can be utilized to enhance the mechanical properties of rubber (such as ductility, elasticity and toughness) by applying either chemical reform or microwave healing according to Da Silva et al. [3] and Lee et al. [8]. The reported results of modified mixture showed good resistance to specific deformation such as rutting depth (by 2.5 times) and fatigue cracking (by 10 times).

In the current research, several experimental works were conducted to enhance performance of asphalt mixture by adding fine particles of RTR as mixture modification. As a result, these modified surface layers may increase pavement stiffness by resisting traffic loads and thereby reduce pavement deformation as well as achieve the optimal use of tyre rubber by recycling process.

2. Methodology

This section involves materials preparation for mix design procedures to prepare modified mixtures. Next, laboratory tests that were adopted in the current study and well described.

2.1. Materials

Four building materials were used to prepare asphalt mixture that were locally supplied in Iraq described as following:

1- Asphalt cement: A penetration grade of 40-50 bitumen was used in the current work. This type of asphalt is widely produced in Samawah oil refinery in Iraq for roads construction. Table 1 presents the physical properties of bitumen 40-50 grade after testing in the laboratory of Samawah oil refinery.

Table 1: Laboratory tests of 40-50 asphalt.

Laboratory tests	Units	Bitumen grade 40-50	ASTM Specification
Penetration 100 gm at 25°C & 5 sec	1/10 mm	43	D5
Absolute Viscosity at 60°C	Poise	3265	D88
Kinematic Viscosity at 135°C	C st	405	D88
Ductility at 25°C & 5 cm/min	cm	132	D113
Softening Point (Ring & Ball)	°C	55.7	D36
Specific Gravity at 25°C	gm/cm^3	1.03	D70
Flash Point (Cleveland Open Cup)	°C	250	D92

2- Natural aggregates: Fine and coarse aggregates were selected from Nagaf quarry. Aggregates were graded into different sizes by sieve analysis. Tables 2 and 3 demonstrate the physical properties of natural fine and coarse aggregates, respectively.

Table 2: Physical properties of natural fine aggregates

Property	Units	Results	ASTM Specification
Bulk specific gravity	gm/cm^3	2.63	C127-88
Bulk SSD specific gravity	gm/cm^3	2.65	C127-88
Apparent specific gravity	gm/cm^3	2.68	C127-88
Absorption	%	1.2	C127-88
Air voids	%	43.5	C1252-23

Table 3: Physical properties of natural coarse aggregates

Property	Units	Results	ASTM Specification
Bulk specific gravity	gm/cm^3	2.65	C127-88
Bulk SSD specific gravity	gm/cm^3	2.67	C127-88
Apparent specific gravity	gm/cm^3	2.69	C127-88
Absorption	%	1 %	C127-88
Fractured particles	%	92% (Min 90%)	D5821-3
Resistance to degradation of mineral aggregate using LA abrasion machine	%	21% (Max 30%)	C131

3- Filler material: Ordinary Portland Cement (OPC) is produced in Samawah cement factory and applied as mineral filler in this study. The physical properties of OPC can be listed in Table 4.

Table 4: Physical properties of ordinary Portland cement.

Property	Results	Specification
% Passing Sieve No. 200	100%	ASTM C117
Liquid limit (L.L %)	25%	SORB/R9 [9]
Plasticity index (P.I%)	3.5%	SORB/ R9 [9]

4- Recycled tyre rubber (RTR): This material was collected from Diwanyaa rubber factory as shown in Figure 1. After cleaning and removing cords from waste tyres, then cutting and sieving were conducted to produce RTR particles that passing sieve No.8 (or 2.36 mm size) and retained on sieve No.50 (or 0.3 mm size).

Fig. 1: Particles of RTR after cleaning, cutting and sieving processes.

2.2. Laboratory tests

Several laboratory tests were carried out in this study based on the standard tests of Marshall methods [10]. The obtained findings will be compared with the Iraqi standards for roads and bridges SORB/R9 [9] as described in the next sections.

3. Mixing Procedures and Sample Preparation

In this research work, two types of asphalt concrete mixtures (AC-I and AC-II) were prepared in the current research work following the AASHTO procedures [11]. Both bituminous mixtures were designed based on aggregate gradation of surface layer type (III-B) as recommended by the SORB/R9 [9] as shown in Table 5 below.

Table 5: Allowable limits of combined aggregates gradation according to SORB/R9 [9].

Sieve opening (mm)	12.5	9.5	4.75	2.36	0.3	0.075
Passing, %	100	90 – 100	55 – 85	32 – 67	7 – 23	4 – 10

To prepare first mixture (AC-I), different sizes of natural fine and coarse aggregates in addition to 5% OPC filler were added then sieved and combined. In this mixture, a certain amount of asphalt binder 40/50 was added and varied between 4%, 4.5%, 5%, 5.5% and 6% to discover the optimum content. No RTR particles were added to this mixture.

In the second mixture (AC-II), dry mixing method was considered for adding RTR. It was suggested to replace half amount of fine aggregates retaining on sieve No.50 (or 0.3 mm size) by RTR particles of (0.3 mm size). The optimum content of 40/50 bitumen was investigated in the design of AC-II mixture by using various percentages between 4% and 6% with increment of 0.5%.

In both bituminous mixtures, the materials were mixed at 160^{o}C temperature and placed in cylindrical mold of 76.2 mm height and 101.6 mm diameter. The samples prepared were placed in Marshall compactor machine at 135^{o}C. Next, samples of 1200 gm weight were shaped after applying 75 blows on the top and bottom bases by a hummer falling from 457.2 mm height. Lastly, the compacted samples were cooled for 24 hr and then prepared for Marshall apparatus. The comparison between Marshall results of both mixtures (AC-I and AC-II) will be discussed in the next section.

4. Results of Laboratory Tests

Following using Marshall mix design method, the compacted samples of two types of asphalt mixtures (AC-I and AC-II) were tested in Marshall apparatus method as shown in Figure 2. To investigate the optimum bitumen content (OBC), Figure 3 illustrates the results of Marshall tests of mixtures AC-I and AC-II. It can be concluded that the results of AC-II in terms of Marshall stability were higher than AC-I data. The OBC can be found by determining the average bitumen contents at peaks of stability and density as well as at specific amount of air voids in total mix. The OBC for controlled mixture was 5.01%, whereas it was estimated at 4.95% in the modified mixture after adding RTR. Determined values of stability and density were achieved at specific amounts of asphalt then they decreased as the asphalt content increased in both mixtures. Also, Marshall flow was accepted within the required range between 2 and 4 mm as stated in the Iraqi specifications [9]. The content of air voids in the mixtures showed reduction trend as the bitumen amount increased, as well as voids in mineral aggregate and those filled with asphalt achieved higher rates as asphalt content increases [9].

Finally, Table 6 presents the results of AC-I and AC-II mixtures that showed good agreement with the allowable thresholds of SORB/R9 [9]. To be concluded, adding RTR might increase the stiffness of the modified mixture as well as reduce the voids percentage in the total mix.

Fig. 2: Marshall apparatus for testing AC-I and AC-II compacted samples.

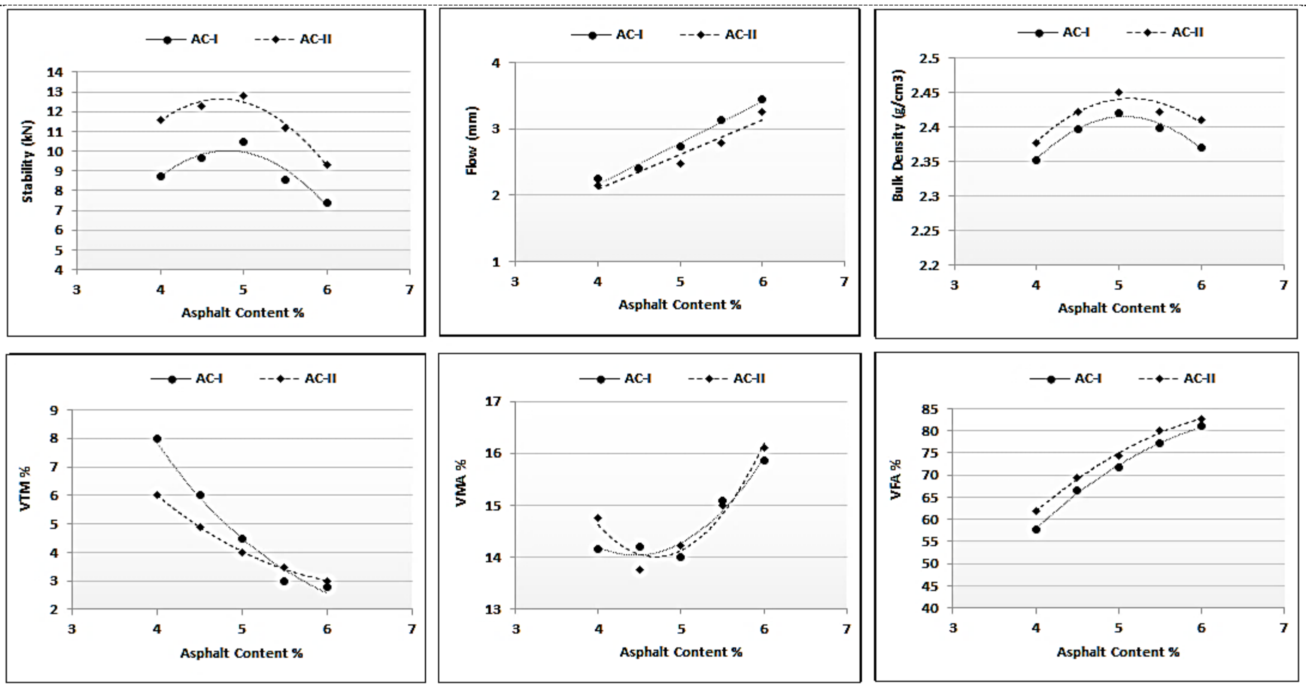

Fig. 3: Marshall tests of AC-I and AC-II mixtures for surface layer.

TABLE 6. Summary of AC-I and AC-II mixtures results according to SORB/R9 requirements.

Marshall properties	Type of surface layer		SORB/R9 specification [9]	Remarks
	AC-I	AC-II		
Optimum bitumen content (OBC), %	5.01	4.95	4.0 – 6.0	Satisfied
Marshall stability, kN	10.50	12.80	Minimum 8.0	Satisfied

Marshall flow, mm	2.80	2.50	2.0 – 4.0	Satisfied
Marshall stiffness, kN/mm	3.75	5.12	Minimum 2.0	Satisfied
Voids in total mix (VTM), %	4.40	4.20	3.0 – 5.0	Satisfied
Voids in mineral aggregate (VMA), %	14.40	14.10	Minimum 12	Satisfied
Voids filled with asphalt (VFA), %	72.00	74.00	65 – 85	Satisfied

5. Summary and Conclusions

This study introduces experimental methods to produce two asphalt mixtures. The first was controlled mixture prepared from natural mixed aggregated without adding RTR. Whereas the second mixture includes a specific content of RTR as a replacement for half amount of fine aggregates retaining on sieve No.50. For sustainability purposes, applying RTR in asphalt mixture is cheap because of availability in huge amounts and causes significant reduction of pollution and landfill areas. The results showed significant improvement in the properties of modified mixture in terms of Marshall stability and flow.

Furthermore, future studies can be addressed as using other types of fillers (e.g. fly ash, oil palm ash, glass powder, nano silica, …etc.) to modify asphalt mixtures containing RTR particles. Resistance to water damage, rutting and creep as well as fatigue tests can be carried out for further investigation. Also, it is essential to compare the results with the allowable limits of Iraqi standards SORB/R9 [9]. Lastly, controlling of job mix, practical test conditions and apparatus maintenance must be double checked to achieve layer thickness design and avoid formation of distresses in the future under prevailing traffic and weather conditions.

Acknowledgement

The authors would express their gratitude and deep thanks to the Department of Civil Engineering / Al-Muthanna University for providing invaluable support and encouragement throughout this study.

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