Research Article

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Improvement of permeable asphalt pavement by adding crumb rubber waste

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Abstract: Designing mixtures of asphalt with a porous structure to gain good trainability decreases both the propagation and generation of traffic noise. Porous asphalt (PA) mixtures use crushed stone, a small proportion of processing sand, admixtures, and asphalt binders. Therefore, this study aims to examine the impact of adding crumbed rubber into the mix of PA. However, the optimum amount of the binder used in the reference mixture without crumb rubber (CR) and the mixture with 10, 15, and 20% of crumbed rubber waste was identified by utilizing drain down. The test of Cantabro loss, air voids, and indirect tests of tensile and permeability were performed on samples to identify the influence of adding crumbed rubber on the features of the PA mixes. The optimum asphalt content achieved is 6.3%. The results indicated that CR decreases PA permeability, while the additional amount of crumbed rubber in PA negatively influences PA characteristics.

Keywords: permeable asphalt pavement, crumb rubber waste, porous asphalt, air voids, permeability

1 Introduction

Porous asphalt (PA) mixture is utilized only as a coarse surface. PA mixture decreased tire splash/spray in rainy areas and naturally produced smoother surfaces than dense-graded hot mix asphalt surfaces. The high air voids trap road noise and decrease tire road noise by up to 50%. The open gradation produces holes in the mixture, which is important to the suitable mix's function. Consequently, anything that tends to clog these holes, such as traffic with low speed, extreme dust or mud on the roadway, or thawing sand, must be prevented [1–3].

An open-graded friction course (OGFC) is a thin permeable layer of asphalt sited on top of conventional dense-graded asphalt pavement. It was produced by studying the plant seal mixes in the 1940s [4]. The seal mixtures provided well-performed unconventional seals of chip and they were widely accepted in America in 1970s. Japan and several countries in Europe also initiated utilizing OGFCs on their road pavements [5].

This kind of asphalt pavement is referred to as porous European mixes (PEMs) in Europe Union countries. They are the same as the OGFC mixes utilized in America, with a few subtle variances. The European mixtures tend to obtain a higher amount of air void, about 18–22%, if the lowest amount of air void quantifies comparison with OGFCs at 15%. The PEMs' gradation has a little extra graded gap, and polymer-modified binders are utilized practically. The variances in the air and gradation amount increase the permeability of PEMs in comparison with the permeability of OGFCs [6]. Moreover, European countries have higher standards for aggregate than America [4,7].

Numerous roads were described to be in good condition after several years in service compared to conventional design. The utilization of crumbed rubber in asphalt mixes has significantly improved in the last years, particularly in America. Satyakumar et al. found the best binder ratio by utilizing asphalt amounts that are limited from 5.5 to 6.5% (optimum asphalt cement ± 0.5%) [8].

The permeable pavement seems to be an established stormwater management solution that may be utilized in parking and low-traffic areas. These pavements can reduce the amount of runoff that reduces the environmental impact compared with a traditional drainage system. Traditional drainage systems, which carry stormwater runoff quickly to a stream by piped systems, cause increases in runoff volume, and peak flow and pollutants are taken to rivers.

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This project aims to investigate the impact of crumbed rubber on PA mixes. The crumbed rubber utilized in improved asphalt mix into two wide-ranging: dry process refers to any technique that mixes crumbed rubber with the aggregate as a modifier before charging the mix with the asphalt binder [9]. The wet process is a technique that blends crumbed rubber with asphalt cement as a modifier before introducing it into the asphalt concrete mixture [10].

Rubber can be utilized in modified-asphalt in two ways:

- In the wet method, the asphalt cement is blended with the crumb rubber (CR) rate before incorporating it into the asphalt concrete mixture.
- In the dry method, the aggregates are mixed with the CR before loading the mixture into the asphalt machine.

In this study, in the wet method, a mixing machine was used with a speed of 2,620 rpm, and the blending temperature ranged from 190 to 200°C for 60 minutes. CR was 10, 15, and 20% by Asphalt cement's weight. These additives' concentrations were selected depending on the suggestions by literature.

2 Materials

The physical characteristics of the asphalt cement utilized in this research are presented in Table 1, and its characteristics respond to the State Corporation specifications for Bridges and Roads [11]. The three-trial grading should be generally within the fine and coarse grating limits, and the gradation was performed according to ASTM, D7064, 2013. The mixing percentage for producing a PA paving mixture should be from 19 mm (3/4 in) maximum aggregate size to 0.075 mm (No. 200) minimum aggregate size. Particle size distribution is shown in Figure 1, which is between the lower and upper suggested gradation limits to meet the gradation requirements by specifications of state corporation for roads and bridges (SCRB) [12] for wearing course type (Table 2). This is also presented in Table 3, which demonstrates the increase in the softening point, and decreasing penetration with increasing the content of crumbed rubber (CR) [13,14]. Three asphalt concentrations were 5.5, 6.0, and 6.5%. The selection of the ratio of asphalt in this study depended on criteria: the peak value of Cantabro abrasion loss is 20% for the unaging abrasion test. In contrast, the percentage for the aging abrasion test is 30%, and the max binder drain down test value is 0.3%.

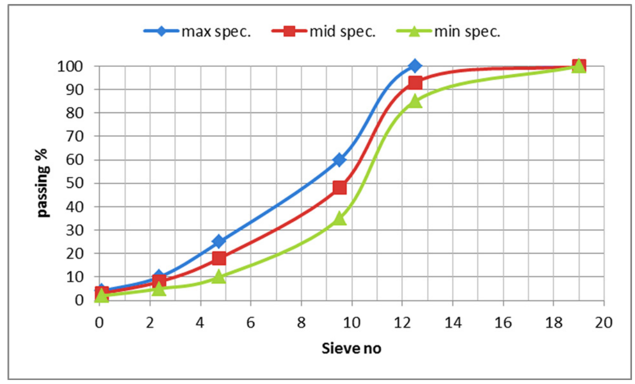

Figure 1: The gradation of aggregate (coarse and fine) depends on [18].

The point of softening and penetration demonstrated in Table 3 for various crumbed rubber concentrations CR1, CR2, and CR3 are asphalt specimens containing cement with (10, 15, and 20)% of crumbed rubber, respectively.

3 Experimental works

The following tests were conducted in Al-Mustaqbal laboratories.

Table 1: Asphalt cement's physical characteristics [15]

Test	Unit	Standard	Value of test	SCRB 2003 specification
Penetration (25°C – 100 g – 5 s)	1/10 mm	ASTM D5	49	40–50
Ductility (25°C, 5 cm/min)	cm	ASTM D113	120	<100
Flash point (cleave land open cup)	°C	ASTM D92	240	<232
Softening point	°C	ASTM D36	54	52–60
Solubility in trichloroethylene	%	ASTM D2042	99.9	>99
Kinematics viscosity at 135°C	CST	ASTM D2170	480	>400
Specific gravity at 25°C	—	ASTM D70	1.02	1.01–1.05
After thin-film oven test				
Penetration of residue (25°C – 100 g – 5 s)	%	ASTM D1754	56	>55
Ductility of residue (25°C – 5 cm/min)	cm	ASTM D1754	32	>25
Loss in weight (163°C – 50 g–5 h)	%	ASTM D1754	0.70	<0.75

Table 2: The aggregates' Physical characteristics

Characteristic	Standard	Coarse aggregate	Fine aggregate		Limitation
			Crushed sand	Natural sand	
Bulk specific gravity	ASTM C127-128 [16]	2.585	2.646	2.641	—
Apparent specific gravity	ASTM C127-128 [16]	2.633	2.687	2.678	—
Percent of water absorption	ASTM C127-128 [16]	0.7	3%	2%	—
Los Angeles abrasion	ASTM C131 [17]	24	—	—	Max 30%

Table 3: Samples details and characteristics

Characteristics	Sample details		
	CR1	CR2	CR3
Crumbed rubber proportions	10%	15%	20%
Penetration at 25°C	40	32	30
Softening point	58	67	71

3.1 Cantabro abrasion loss test

The test of Cantabro abrasion loss is presented in [17]. This test aimed to identify the optimum amount of binder in the mixture of PA. These samples should be examined within 7 days after finishing the compacting of Marshall Mold for two conditions without a conditioning sample. The sample was rotating at a speed of 30–33 rpm for 300 revolts without steel balls at 25°C, as demonstrated in Figure 2. Then, loose material breaking off the sample during testing should be disposed of. Sample blocks are recorded before and after the test, as demonstrated in Figure 3. The percentage of weight loss (Cantabro loss) refers to PA's durability and relates to the asphalt binder's quality and the amount of the asphalt. The loss in the sample's weight is expressed in the percent of dissolved particle weight by the primary sample weight, as demonstrated in equation (1).

$$\%\,\text{L.A abrasion} = \frac{(A - B)}{A} \star 100, \qquad (1)$$

where A is the initial specimen weight (before putting in the drum of Los Angles abrasion (L.A)) (in grams) and B is the final weight for the specimen (after 300 revolutions in the drum of L.A abrasion) (in grams).

3.2 Drain down test

This test was performed on specimens to check whether they exceeded the limited value of 0.3% according to refs. [19–21], and an un-compacted mixture at optimal binder content is placed into a basket's wire on a weighted plate that weighs 1.1 kg. The whole set of tests is put in a forced drying furnace, which can maintain a temperature between 120–175°C and 250–350°F within ±2°C (±3.6°F) for an hour, as shown in Figure 3.

$$\%\,\text{Drainage loss} = \frac{D - C}{B - A} \star 100, \qquad (2)$$

where A is the unfilled wire basket mass (grams), B is the (wire basket + sample) mass (grams), C is the unfilled steel or paper container mass (grams), and D is the container of (steel or paper) + mass of drained material (asphalt cement and aggregate) after oven drying for 1 h (grams).

3.3 The test of permeability

This testing technique was placed as a standard testing method, and the test procedure was as outlined in ASTM PS 129-01 [20] for the permeability of bitumen materials. The permeability device placed in the lab consists of a cylinder of aluminum with dimensions (length = 13 cm and internal diameter = 11 cm). The cylinder contained an internal rubber sleeve to prevent the horizontal flow and make the vertical flow down. The water utilized in the experiment must be set at a temperature of 20°C to utilize Darcy's law falling head permeability test. The apparatus is demonstrated in Figure 4. The coefficient of the permeability (K) was determined depending on the law of Darcy test of falling head permeability, utilizing the following formula:

$$K = \frac{a}{A}\,\frac{L}{t_2 - t_1}\,\ln\frac{h_1}{h_2}, \qquad (3)$$

where K is the permeability coefficient (cm/s), a is the area of the cross-section for a testing tube (cm^2), L is the thickness of the sample (cm), A is the area of cross-section for sample (cm^2), h_1 is the primary head (in.), h_2 is the final head (in.), and t_2 and t_1 are the corresponding time (s) to h_2 and h_1, respectively.

Figure 2: Los Angeles abrasion test.

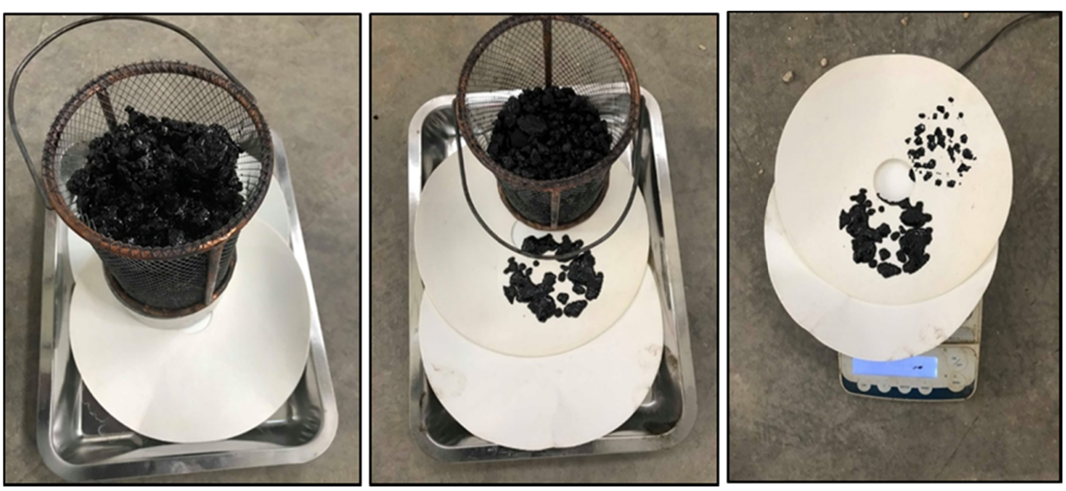

Figure 3: Asphalt drain down test for Basket before and after 1 h.

3.4 Indirect tensile test

The damage caused by moisture is considered one of the most distressing forms, leading to intensifying and initiating other distresses. AASHTO T 283 [22] should identify the susceptibility for the specified mix as a testing technique. This test will measure the ratio of indirect tensile strength for the conditioned specimens to indirect tensile strength for dry specimens, representing a criterion for evaluating the resistance of samples to moisture damage. The retained tensile strength (RTS) must be 80% at least, the number of air voids should be around 18–22%, and samples were immersed in the water for 24 hours at 60°C, which significantly decreases the tensile strength value as demonstrated in Figure 5. Furthermore, this partly returns to the reality that assuming the pavement's service life will be subject to different climatic and traffic loading conditions.

Moreover, these cases might be caused by developing the tensile stresses in the pavement mass, which appear in two kinds of cracks. The first type of crack is named fatigue cracking, which results from traffic loading. Simultaneously, the second type of crack resulted from climatic influences and was named shrinkage or thermal

Figure 4: Hydraulic conductivity apparatus.

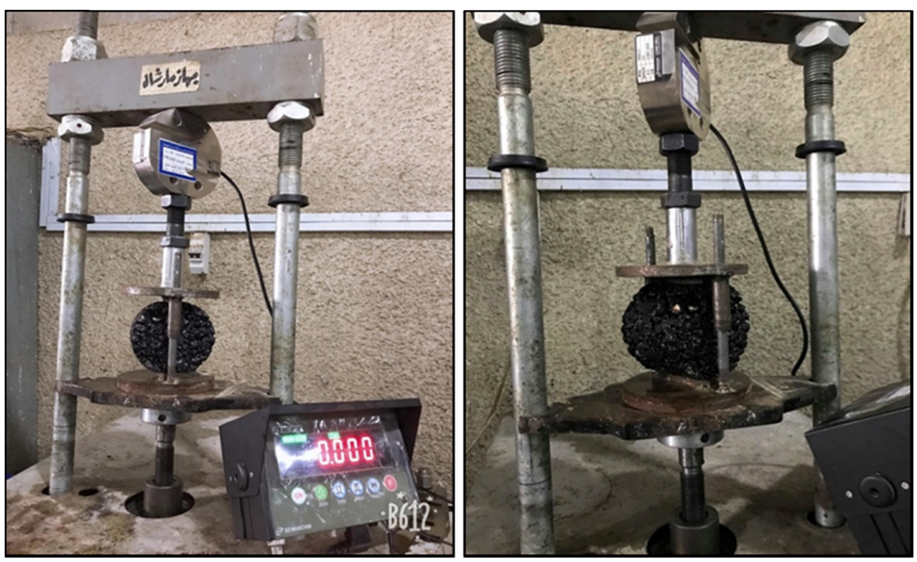

Figure 5: The indirect tensile test by Marshall device.

cracking. The following equations are used to compute an indirect tensile strength test (ITS).

$$\mathrm{ITS} = \frac{2\mathrm{Pu}}{\pi DL}, \tag{4}$$

where Pu is the ultimate load (kN), D is the diameter of the marshall sample (m), and L is the Marshall sample's height (m). RTS is the wet/dry ITS ratio expressed as a percent.

4 Experimental work outcomes and discussion

4.1 The results of the Cantabro aged test

As shown in Figure 6, the Cantabro test result indicates that all mixtures are within specification loss of abrasion limit if the test of Cantabro abrasion does not exceed 30%

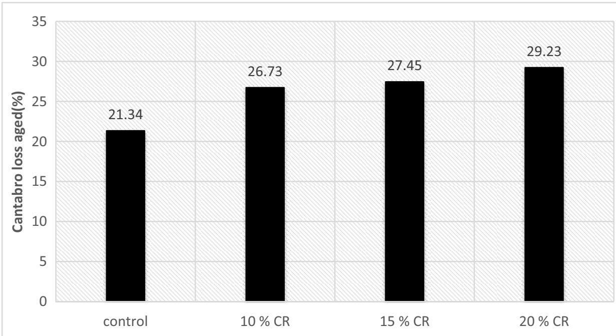

Figure 6: The results of the Cantabro aged test.

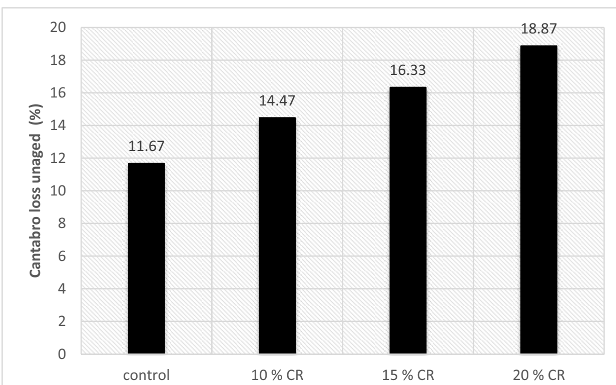

Figure 7: Results of the unaged Cantabro test.

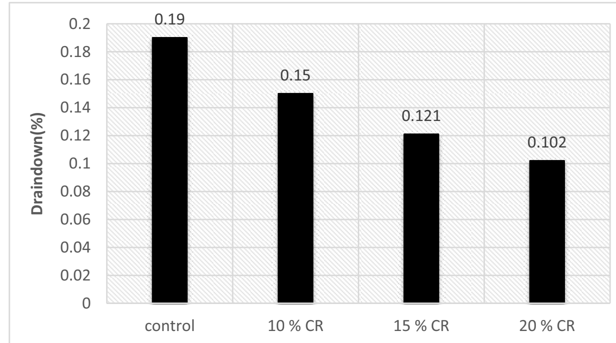

Figure 8: Results of the test's drain down.

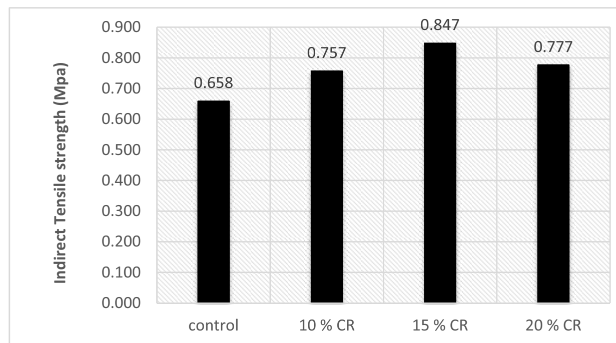

Figure 9: ITS results.

as an average. In comparison, the loss for any individual specimen should not exceed 50%.

As demonstrated in Figure 7, the Cantabro test result indicates that all selected mixtures were satisfied with the mean loss of abrasion for the test of Cantabro, which should not be exceeded by 20%.

4.2 Results of the test's drain down

As demonstrated in Figure 8, all selected mixtures accept the highest allowable 0.3% requirement. An increase in crumbed rubber content decreases the amount of drain down since rubber improves thermal asphalt cement sensitivity by incrementing the viscosity of asphalt.

4.3 The results of the test's indirect tensile strength

As demonstrated in Figure 9, the mixture containing 15 and 20% CR has greater dry ITS than the control and mixture with 10% CR. Figure 10 demonstrates that the mix with 10% of crumbed rubber is the lowest moisture-influenced mix type among all specified mixes. Furthermore, the increase in the crumbed rubber shows a decrement in the ratio of wet/dry ITS, which reduces the mixture's resistance to moisture damage. However, crumbed rubber positively influences moisture susceptibility, and it maintains until reaching a suitable amount between 10 and 15%. Moreover, all selected mixtures were satisfied with the specification limit for tensile strength ratio (TSR) = 80%.

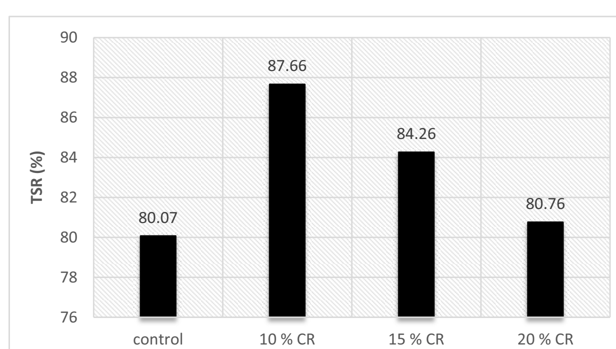

Figure 10: Wet/dry ITS results.

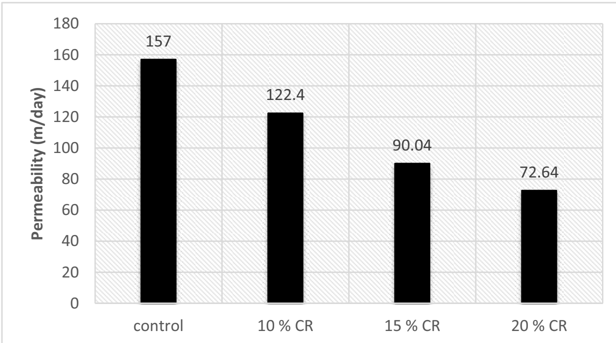

Figure 11: Permeability test results.

4.4 Permeability test results

As shown in Figure 11, the permeability test result indicates that control and 10% CR mixtures are within the specification limit (greater than 100 m/day). The water utilized in the experiment must be set at a temperature of 20°C to utilize Darcy's law falling head permeability test. The coefficient of permeability reduces with an increased percentage of CR. Using 10% of CR in the mixture decreased the permeability by 8%. In comparison, by 15% CR, the effects of the permeability are decreased to 17%, and by using 20% CR, the permeability was decreased by 29% from the control asphalt content value. Increasing the content of CR in the mix decreases the permeability coefficient.

5 Conclusion

This research aims to investigate the impact of utilizing various crumbed rubber proportions on the PA mixes performance where the following results have been obtained:

- The medium aggregate grading is considered the best grading. The best amount of asphalt is identified by the mean higher limit of the binder for the test of drain down, the minimum limit from a test of Cantabro, and the required amount of air void. In this research, the wet method with optimal binder content shows 6.3% for the PA mixtures. The weight loss results in Cantabro indicate that crumbed rubber accelerates aging. Moreover, the crumbed rubber decreases the draining down the possibility of PA and permeability.
- With the increasing crumbed rubber, there was an initial increase in TSR, followed by a decrease. Nevertheless, in the ranges of crumbed rubber utilized in this research, it was observed that the use of crumbed rubber increased the resistance to moisture damage for the PA.

6 Recommendation

The authors recommended applying other by-products or waste materials [14,23–25]. For instance, stainless steel powder, silica fume, paper waste, crude oil wastes [26–28], agricultural waste [29], industrial wastes, municipal solid wastes, as well as water and wastewater planes waste [3] to improve the produce mortar. As well as using crumbed rubber as an admixture for high-performance asphalt blend enhances the durability and rutting resistance of the PA mixture. It can be concluded that the case of 10 and 15% contents of the crumbed rubber must be utilized to enhance PA mixture's performance features; the content of rubber higher than 15% decreases the performance of the mixture significantly.

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