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RESEARCH ARTICLE

Investigating the Effects of Using Crumb Rubber in Hot Mix Asphalt Surface on Skid Resistance Properties aliukm@yahoo.com

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Abstract

Utilization of discarded tires of vehicles in pavement construction was one of solutions that could improve performance of HMA and solve waste problem to achieve sustainable development, the aim of this study to investigate the effect of utilizing crumb rubber on the skid resistance properties of HMA by using dry method. Crumb rubber is the recycled rubber obtained by mechanical shearing or grinding of tires into small coarse crumb rubber. Skid resistance is the most important property of pavement surface that must be taken into consideration in the design of roads and should be adequate to resist skidding of vehicles to ensure the safety of human life. The British Pendulum Tester (ASTM E303) and The Volumetric Method (Sand Patch) (ASTM E965) are the main tests for the skid resistance.

The dry method includes mixing the crumb rubber particles with aggregates prior to addition to asphalt and the crumb rubber does not fully react with the asphalt, The investigation was conducted by preparing 17 specimen include (1, 2 and 3%) crumb rubber content and (No. 6, 8, 12, 16 and 50) crumb rubber size (as aggregates and as additive).The skid resistance (F60) has been decreased by (117%) when using crumb rubber size No.6 as aggregate in asphalt mixture, and increasing crumb rubber content from (1 to 3 %) of total mixture has decreased skid resistance (F60) by (124%). While using crumb rubber as additive in asphalt mixture improving the skid resistance properties.

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1. INTRODUCTION

Pavement–tire friction (or simply pavement friction) is one of the primary factors determining highway safety and, in particular, the probability of wet skidding crashes. Highway agencies have recognized this fact since the 1920's. The probability of wet skidding crashes is reduced when friction between a vehicle tire and pavement is high^[1]. Pavement surfaces should provide adequate friction and maintain a good level of ride quality to

ensure satisfaction of the driving public. In particular, it is important for the safety of the driving public that roads provide adequate friction at the tire-pavement interface. The combination of good friction, low levels of roughness, and low levels of noise are important in pavement wearing surface design. Approximately 15% of fatal and injury causing accidents occur during wet weather, some of which are due to friction deficiencies at the pavement surface^[2] (Smith 1976). The accidents are a result of numerous reasons including driver error, vehicle malfunction, and friction deficiencies at the

tire-pavement interface. Accidents resulting from a friction deficiency of the pavement surface are more likely to occur with the accumulation of precipitation such as rain^[3]. A film of moisture on the pavement surface, resulting from precipitation, may prevent vehicle tires from making adequate contact with the surface of the road. Unfortunately, increasing pavement friction also has negative aspects. They include increased fuel consumption, tire wear, and noise inside the vehicle. However, the negative aspects of increasing pavement friction are outweighed by the potential decrease in the number of accidents occurring from inadequate pavement friction^[4]. The roadways as one of the element of infrastructure play a vital role in supporting the quality of life. Infrastructure and its utility services need to be efficient and to be geared towards supporting a clean and high quality environment. Utilization of rubber in pavement construction is one of the smart solutions in sustainable development by recycling waste material and also extends the period of time services of the road. Thus, rubber especially coarse crumb rubber could be as one of alternatives material in enhancing the performance of hot mix asphalt^[5]. Utilization of crumb rubber by dry method in HMA improving the asphalt mixture properties to rut and fatigue resistance but effecting on skid resistance properties of asphalt mixture. Thus, the aim of this study is to investigate the effect of using crumb rubber in HMA surface on skid resistance properties by dry method.

2. CRUMB RUBBER PRODUCTION

Grinding or cryogenic processes can be used to produce the crumb rubber that will be incorporated in the asphalt rubber. The grinding Method: that is basically tearing and crushing the old tires at ambient temperature. A combination of grinders or granulators followed by sieves, transport conveyers and different kinds of magnets are used to crush and extract the steel of the carcass. The grinding process method has been widely adopted and is also more productive to obtain the crumb rubber. The cryogenic Method: that is carried at very low temperatures (-87 to -198) C°. In this case, the rubber of the tires is dipped into liquid nitrogen. At very low temperatures, the rubber becomes very brittle and it can be easily pulled apart on a press, into the desired particle dimensions. These particles of crumb rubber have lower specific surface than the ones obtained by the grinding process^[6].

3. ASPHALT RUBBER PRODUCTION

There are two processes for producing asphalt-rubber, known as the wet process and the dry process.

1. The wet process, called asphalt-rubber, in the wet process, a straight binder is initially preheated to around 190C°, then crumb rubber is added. The digestion process, which is the incorporation of rubber in the conventional binder, continues for a period of (1 to 4) hours, at a temperature of (190) C°. The process is facilitated by a mechanical agitation produced by a horizontal shaft.

2. The dry process, called aggregate-rubber, in the dry process, particles of crumb rubber are added to preheated aggregates before the addition of the straight bituminous binder. Aggregates are heated to temperatures of approximately (200) C°, then crumb rubber is added and mixed for about (15) seconds until a homogeneous mixture is obtained. Straight binder is then added in a conventional mixing plant. And the principal differences between these processes include:

1. size of rubber: the dry process rubber is much coarser than wet process rubber.

2. amount of rubber: the dry process uses (2 to 4) times as much as the wet process.

3. function of rubber: in the dry process the rubber acts more like an aggregate but in the wet process it acts more like the binder.

4. ease of incorporation into the mix: in the dry process no special equipment is required while in the wet process special mixing chambers, reaction and blending tanks, and oversized pumps are required^[7].

4. PAVEMENT FRICTION PRINCIPLES

Pavement friction is the force that resists the relative motion between a vehicle tire and a pavement surface. This resistive force is generated when the tire rolls or slides over the pavement surface.^[8]

Mechanisms of Pavement Friction Pavement friction is the result of a complex interplay between two principal frictional force components: adhesion and hysteresis. Although there are other components of pavement friction (e.g., tire rubber shear), they are insignificant when compared to the adhesion and hysteresis force components. Thus, friction can be viewed as the sum of the adhesion and hysteresis frictional forces^[8].

Adhesion is the friction that results from the small-scale bonding/interlocking of the vehicle

tire rubber and the pavement surface as they come into contact with each other. It is a function of the interface shear strength and contact area. The hysteresis component of frictional forces results from the energy loss due to bulk deformation of the vehicle tire^[8].

5. FRICTION MEASUREMENT METHODS:

ASTM has developed a set of surface characteristic standards and measurement practice standards for both friction and texture. These standards ensure comparability of the measurements for specific purposes; they are grouped according to measurements performed at highway speeds (i.e., high-speed devices) and measurements requiring lane closure (i.e., low-speed/walking and stationary devices)^[8].

The International Friction Index (IFI) was developed during the PIARC International Experiment to compare and Harmonize Texture and Skid Resistance Measurements to overcome the differences among measurement devices^[9]. The IFI uses measurements of skid resistance and texture to evaluate the pavement surface characteristics and is being adopted worldwide for skid resistance comparison. To calculate the IFI it is necessary to have at least one friction measurement and one macrotexture measurement (ASTM E1960). The IFI is reported in two parameters: the normalized friction value at 60 kilometers per hour (F60) and a speed constant related to the pavement friction value (Sp)^[10].

The speed constant, Sp, is calculated using Equation $Sp=a+b*TX$ (1)

The constants a and b are dependent on the measurement method used to obtain the macrotexture parameter TX in millimeters. The applicable values for the texture measurements used in that research are shown in Table (1).

Table (1): Constants for Speed Constant Equation^[10]

TX (mm)	a	B
MPD (ASTM E 1845 Standard Practice for Calculating Pavement Macrotexture Depth)	14.2	89.7
MTD (ASTM E 965 Test Method for Measuring Pavement Macrotexture Using a Volumetric Technique)	-11.6	113.6

While the normalized friction value (F60) is calculated using Equation (5):

$$F60=A+B*FR60+C*TX \dots\dots\dots(2)$$

Where: F60 = Normalized friction value,
 A, B, and C = Calibration constants,
 TX = Macrotexture measurement in millimeters .

The parameters used in Equation (5) are shown in Table (2).

Table (2): The values for the parameters for Calculating F60^[10].

Tire Type Used	Slip Speed (km/hr)	A	B	C
Blank	65	0.045	0.00925	0.000
	60	0.0436	0.0095	
Ribbed	65	-0.023	0.00607	0.098

MICRO TEXTURE AND MACRO TEXTURE:

Micro texture is primarily a property of the individual pieces of aggregate making up the road surface. The micro texture of the aggregate controls the contact between the tire rubber and the pavement surface. In the provision of sufficient frictional resistance to bring a moving vehicle to a stop, microtexture provides the primary source of frictional resistance at low speeds (less than 50 km/h) due to the direct interaction between the tire rubber and the aggregate surfaces^[11].

The macrotexture of the pavement surface refers to the coarser texture defined by the shape of the individual aggregate chips and by the spaces between the individual aggregate chips. Macrotexture is particularly important in relation to wet conditions. In traditional surfacing materials, the individual aggregate chips provide a capability to penetrate a water film on the pavement surface, while the spaces between the aggregate chips provide drainage paths for the water to be dispersed^[11].

MATERIALS AND TESTING PROCEDURE:

The materials used in this study are locally available in Iraq. The properties are evaluated according to AASHTO and ASTM standards compared with the State Corporation of Roads

and Bridges (SCR/R9, 2003) ^[15] specification requirements.

The Asphalt Cement is one grade of asphalt cement (40–50) penetration graded from Al-Dourah refinery is used. The physical properties and tests of the used asphalt cement are shown in Table (3).

Table (3): The Physical Properties and Tests of the Used Asphalt Cement.

Property	ASTM Designation	Test Result	SCR/R9 Specifications
Penetration (25 C ⁰ , 100 gm, 5 sec), (0.1 mm)	D-5	43	(40 – 50)
Kinematic Viscosity at 135 C ⁰ , (cst).	D-2170	405	
Ductility (25 C ⁰ , 5 cm/min), (cm)	D-113	107	> 100
Flash Point (Cleveland open cup), (C ⁰)	D-92	275	232>

The Aggregate and Filler source of the aggregate used in this study is Al-Niba'ee quarry. This aggregate is widely used in Iraq for asphalt mixtures works, and maximum size for aggregate is 12.5 mm (0.5 in.) and the physical properties of the used aggregate are shown in Table (4). And mineral filler have been used including was cement from Karbala governorate.

Table (4): Physical Properties of the Used Aggregate.

Property	ASTM Designation	Course Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127 & C-128	2.63	2.63
Apparent Specific Gravity	C-127 & C-128	2.68	2.76
% Water Absorption	C-127 & C-128	0.5	2.8

SKID RESISTANCE TESTS :

Macrotexture Measurement (Volumetric Method) Traditionally, texture depth measurements have been carried out as a measure of pavement macrotexture. The sand patch or volumetric patch test is by far the most commonly prescribed test worldwide. It is covered in numerous national and international specifications including ASTM E965^[12]. The test basically consists of a known volume of standardized sand or small glass spheres being spread out over the pavement surface using a flat disk. The sand are distributed to form a circular patch. A small circle diameter indicates a high average texture depth; a large circle diameter indicates a low average texture depth. The volume of sand (known) divided by the surface area covered by the sand (measured on site) yields the average texture depth.

Microtexture Measurement (British Portable Skid Resistance Tester) As already discussed, direct measurement of microtexture is not feasible due to the microscopic nature of the factors influencing differences between aggregate sources. On pavement surfaces, the polishing susceptibility of a particular stone under the scrubbing action of vehicle tires at the tire/surface interface is of primary interest.

The British Pendulum Tester is described in ASTM E303^[13]. Basically, it consists of a swinging arm with a rubber slider base. The arm is released from a specified height, and allowed to swing down, acting as a pendulum. At the lowest point of the swing arc, the rubber slider comes in contact with a prepared surface of aggregate to be tested.

PROPERTIES OF MIXTURES:

In this study, the properties of asphalt mixtures used in testing (Volumetric Test and British portable Tester) are:

- Asphalt Cement Grade: (40-50).
- Filler Type: Cement.
- Mixing and Compaction Temperature: (160 and 130) C⁰ respectively.
- Aggregate maximum mineral size: (12.5) mm.
- Asphalt Content: AC% (4.7) %.
- Dry Surface condition. And the testing variables for asphalt concrete mixtures include the following:
 - Course crumb rubber size (No.6, 8, and 12) as Aggregate. and replacing by No.8 of Aggregate.

- Fine crumb rubber size (No. 50) as Aggregate.. and replacing by No.50 of Aggregate.
- Crumb rubber Content (1, 2, and 3)% of total mix.
- Crumb rubber size (No. 6, 8, 12 and 50) as additive and 2% content of total mix.

PREPARATION OF SPECIMENS:

The aggregate are first dried to a constant weight at (110) C°, separated to the desired size by sieving and recombining with the mineral filler to conform the selected gradation requirements of SCRB (2003) specification for surface course. All aggregate sizes and filler are placed in the mixing bowl. The aggregate and the filler are heated before mixing to temperature (160) C°.

The Preparation of Binder Asphalt cement is heated in an oven to 160C° temperature before weighting the desired amount and then mixing.

After completion of original asphalt preparation, the binder is weighted to the desired amount and then added to the heated aggregate in the mixing bowl and the weight of used additives is added too. All components are mixed until all aggregate and filler particles are coated with the binder. After mixing thoroughly the material was cast in the specially made steel mold (150×100×75mm), then the casted mixture was compacted by a hand compactor with 88 blows each face.

BRITISH PENDULUM TESTER:

The procedure for determining the British Pendulum Tester (BPN) of different surfaces follows as:

1. The tester was placed on the tested surface.
2. The base was leveled by means of three leveling screws.
3. The head was raised so the pendulum arm was clear to the surface.
4. The head of the tester was lowered until it just touched the surface and was able to be rotated until it reached the end of contact.
5. The length of contact was compared with the length of the measuring device provided and the pendulum length was adjusted until the correct length was obtained.
6. The pendulum was raised and clamped horizontally in place.
7. The test area and slider were wet.
8. The pointer was moved until it stop.
9. The pendulum was released and caught on the return swing before it struck the surface again.

10. The value shown by the pointer was recorded.
11. This process was repeated four times and the results averaged.

VOLUMETRIC METHOD:

1. Procedure for this test consists of placing a known volume of material (V) on the pavement surface.
2. Spreading it using a circular motion until the sand is dispersed around the voids in the pavement surface.
3. The diameter of the area (D) covered with the sand is measured.
4. Then the mean texture depth (MTD) of the pavement macrotexture is calculated using the following equation (ASTM E965)^[14].

$$MTD=4V/(\pi D^2)(MM^3/MM^2).....(3)$$

INTERNATIONAL FRICTION INDEX.

Methods are available for conversion of skid resistance parameters to the IFI .The IFI can be estimated (in Metric form, as outlined in ASTM E 1960) by following the steps below.

1. Measure Macro-texture: measure pavement macro-texture and compute MTD (ASTM E 965) (in millimeters).
2. Estimate the IFI Speed Number SP: Using the computed MTD, calculate SP (in km/hr) as follows

$$SP = -11.6 + 113.6 \times MTD(4)$$

3. Calculate the IFI Friction Number F(60): BPT results can be converted to F60 values through the relationship:

$$F60=0.0436+0.0095*BPN *exp (-50/ SP)..(5)$$

RESULTS OF EXPERIMENTAL WORK:

Effect of Crumb Rubber Size on Skid Resistance

It is well known that the crumb rubber size is the major contributor to skid resistance properties of asphalt mixture. The British Pendulum Tester (BPN) and mean texture depth (MTD) testing were conducted for five sizes (sieve No.): (6, 8, 12, 16, and 50). The course (No. 6, 8, 12, and 16) and fine (No. 50) crumb rubber replacing by (No. 8) and (No.50) of aggregate respectively.

The results of BPN, MTD, and F60 tests are presented in Figures (1,2, and 3) respectively, it

is clear from these Figures that the crumb rubber size had significant influence on the skid resistance and the skid resistance properties decreasing with crumb rubber size increasing because the crumb rubber had surface texture more smooth than crushed aggregate

Figure (1): Influence of (crumb Rubber size as aggregate) on (BPN).

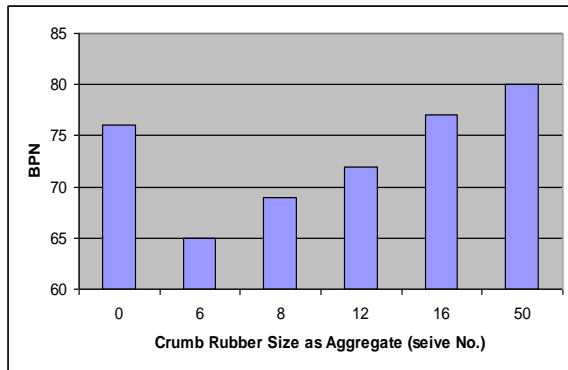


Figure (2): Influence of (crumb Rubber size as aggregate) on (MTD).

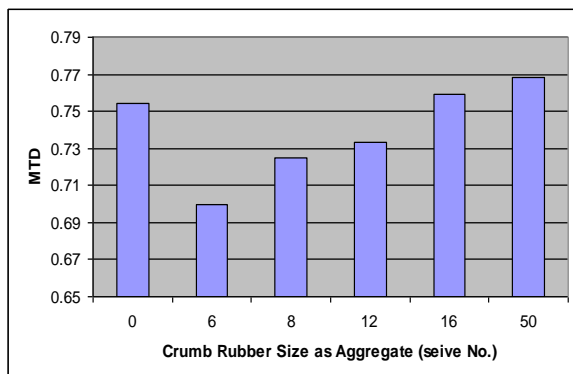
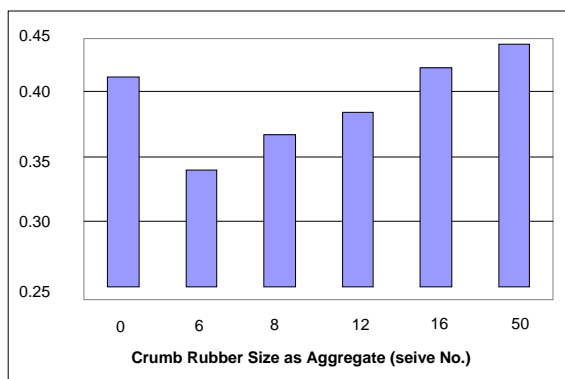


Figure (3): Influence of (crumb Rubber size as aggregate) on (F60).



Effect of Crumb Rubber Content on Skid Resistance

The British Pendulum Tester (BPN) and mean texture depth (MTD) testing were conducted for three content: (1, 2, and 3%) of total mixture for crumb rubber (No. 6, 8, and 12) only.

The results of BPN, MTD, and F60 tests are presented in Figures (4,5, and 6) respectively. It can be seen from these Figures that with the increasing of crumb rubber content, skid resistance properties decreases.

Figure (4): Influence of (crumb Rubber Content (%)) on (BPN).

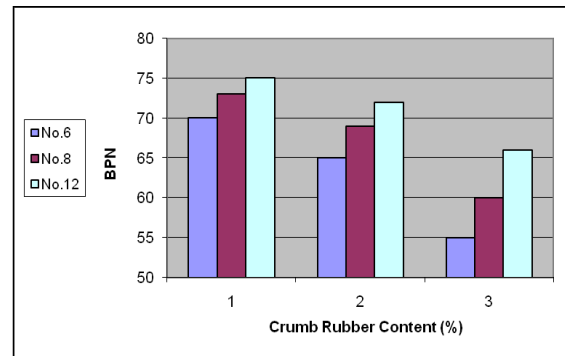


Figure (5): Influence of (crumb Rubber Content (%)) on (MTD).

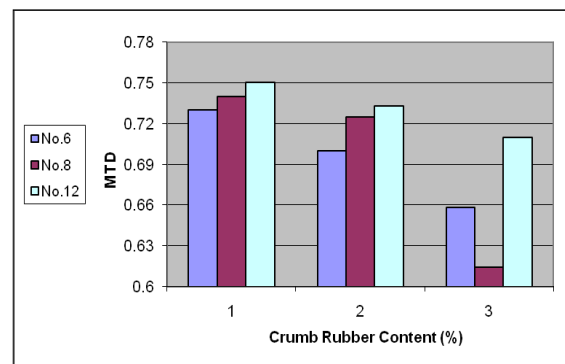
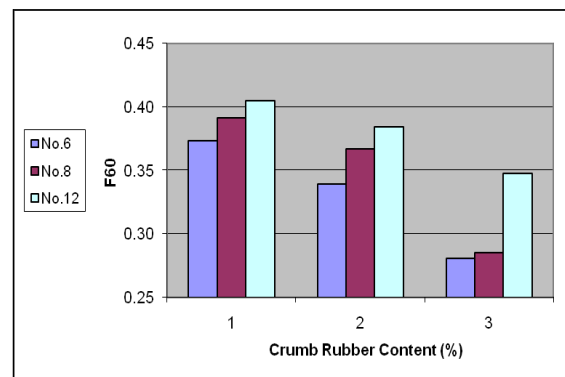


Figure (6): Influence of (crumb Rubber Content (%)) on (F60).



Crumb Rubber as Additives

The adding type of crumb rubber had significant influence on the skid resistance properties. The British Pendulum Tester (BPN) and mean texture depth (MTD) testing were conducted at two addition type: (one as aggregate and other as additive).

The results of BPN, MTD, and F60 tests are presented in Figures (7,8, and 9) respectively. It is clear from these Figures that the crumb rubber as additive had skid resistance higher than the control mixture and the mixture had crumb rubber as aggregate.

Figure (7): Influence of (crumb Rubber size as Additive) on (BPN)

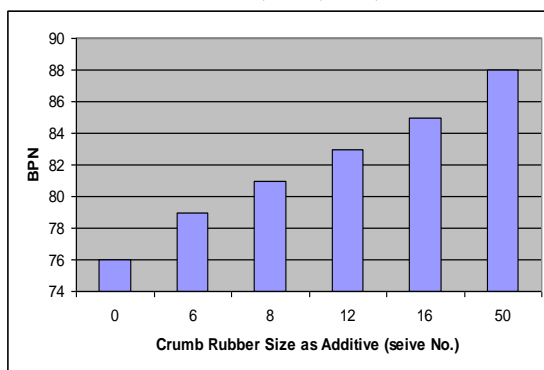


Figure (8): Influence of (crumb Rubber size as Additive) on (MTD).

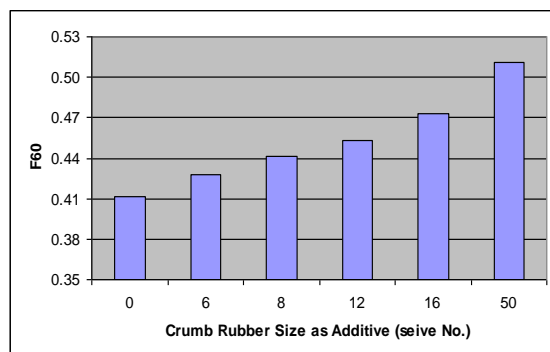
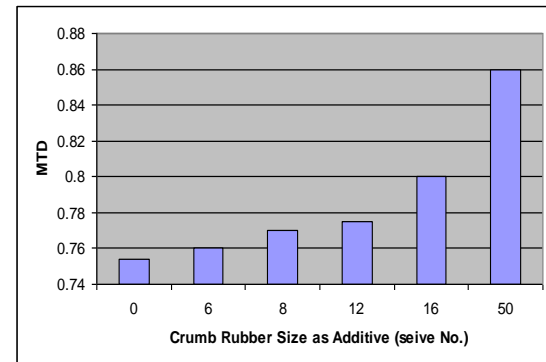


Figure (9): Influence of (crumb Rubber size as Additive) on (F60).



CONCLUSION

From the results shown in previous study the following conclusions can be drawing:

1. Friction Number (F60) has been decreased by 117% when using crumb rubber size No.6 as aggregate in asphalt mixture.
2. Decreasing crumb rubber size from No.6 to No.50 has increased Friction Number (F60) by 130%.
3. Increasing crumb rubber content from 1 to 3 % of total mixture has decreased Friction Number (F60) by 124%.
4. Using crumb rubber as additive in asphalt mixture improving the skid resistance properties.
5. Finally, according to results presented in this paper, Recommended to Study the effect of using crumb rubber in asphalt mixture by wet method on skid resistance properties.

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