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The Effect of Using Crushed Boulder Aggregate on HMA Performance

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Abstract:

Shear strength of the asphalt mixture (Marshall Stability) decreases as the percentage of rounded particles increases, which makes the mixture more susceptible to Permanent Deformation. According to SORB[1] specifications revised 2004 (R9), for prepare bitumen base layer for Hawler- Perda Highway project (new direction), the max. nominal size, (25.4 mm) of aggregate at three different crushed boulders levels: 0% (all was rounded), 50%, and 100% (more than one fracture face), added to Two different asphalt penetration grade types (40-50), and (60-70) were used to prepare the specimens. Specimens were prepared a total of 108 specimens for performance evaluation tests. It has been shown that Crushed boulders mixtures have marshall stiffness value more than 250% (100% crushing), increase VMA (voids in mineral aggregate) more than 130%, and to increase the resistance of moisture damage 135% in comparison with rounded mixtures respectively.

Keywords: Crushed aggregate, HMA performance, Hot mix asphalt, Marshall design method.

INTRODUCTION:

Permanent Deformation (Rutting) and Moisture Damage Induced (stripping) are two kinds of pavement distresses that can cost transportation agencies millions of dollars in maintenance and rehabilitation. Various research studies have been conducted to examine different characteristics of performance of asphalt pavements. This study examined the effect of crushed aggregate content on the performance of HMA. Usually, laboratory Marshall (stability and flow) device has been used to measure stiffness of specimens (indicator of rutting resistance), Indirect tensile strength test of specimens at two (low and high) temperatures as guides of temperature susceptible, and index of retained strength as indicator of moisture damage resistance that were used to evaluate the performance of specimens prepared at different crushed aggregate content levels.

BACKGROUND:

Mineral aggregates make up between 80% and 90% of the total volume or 94% to 95% of the mass of hot mix asphalt (HMA). For this reason, it is important to maximize the quality of the mineral aggregates to ensure the proper performance of our nation's roadways. The quality of mineral aggregates for road-paving materials has been specified by the toughness, soundness (durability), cleanliness, particle shape, angularity, surface texture, and absorption. Previous researches have shown that crushed aggregate content is an important factor affecting the rutting performance of HMA. On the other hand, some studies concluded that the crushed aggregate content is only of minor importance in rutting performance.

Hicks et al. (1985) studied the effect of percent fracture and gradation on the behavior of asphalt concrete. The crushed aggregate contents studied were 50%, 70%, and 90%. Aggregate blends were prepared using three aggregate sources in Alaska. They concluded that the threshold value of 70% crushed aggregate content, which is the current Alaska crushed aggregate content specification, was a very suitable aggregate design [2].

Wedding and Gaynor carried out a research study to determine the effects of crushed coarse and fine aggregate in HMA. Specimens with different percentages of crushed aggregate were prepared and tested. The Marshall stability value was used as the performance indicator. It was concluded that using more than 75% coarse crushed aggregate particles does not significantly contribute to the stability and increases the cost [3].

The National Center for Asphalt Technology at Auburn University developed a model to establish a relationship between rut depth and aggregate properties. Crushed aggregate content was one of the variables in the study. Researchers found that as the crushed aggregate content decreases, the rate of rutting increases [4].

In this study, Marshall mixes will be designed for bitumen base course. One of the advantages of the Marshall Mix Design method is that the performance of the mixes can be expected for local materials and environmental impact. The experimental work in this study provides a comparison among six types of mixtures using two types of asphalt in addition of two types of aggregates, one was pure rounded (river sieved), and crushed boulders (larger than 37.5 mm) in two ratios (50%, and 100%).

The work was limited to one type of gradation, (One nominal maximum size aggregate 25.4 mm for bitumen base coarse as one source of aggregate as (after sieving by use 37.5 mm to make rounded aggregate) and (retained on sieve 37.5 mm as boulders to crush it to introduce the crushed fractions of 25.4 mm, 9.5 mm, and 4.75 mm) was used in these mixes.

Experimental work and results:

Materials:

The virgin materials used in this study are widely available and currently used in road paving in Iraq. All materials are obtained from commercial sources.

i. Asphalt Cement:

Two types of asphalt grades were used, the (40-50), and (60-70) penetration grade asphalt cements from Baijy refinery (Iraq) are used. The physical properties and tests of this asphalt cement are presented in Table (1)

ii. Aggregate:

The source of aggregate is Perda quarry. The physical properties of aggregate (river ,rounded) and crushed aggregates are shown in Table (2), and Table (3) respectively. In order to produce an identical, aggregates are sieved in the laboratory to prepare the selected gradation for both types of aggregates, the aggregate maximum size being (37.5 mm).

iii. Mineral Filler

The mineral filler (lime stone dust) used brought from Erbil factories (khatawa sector)) % passing sieve No.200 is equal to 96% with a specific gravity of 2.74.

Testing procedure:

1. Preparation of Specimens (Marshall design method):

Marshall Specimens are used to determine the Index of retained strength, compressive strength, stability, plastic flow, and indirect tensile strength. These specimens are prepared in accordance with the requirements of ASTM D-1559

(Specimen dimensions, D=100.16, H=63.5 mm). The Hot Mixes Asphalt (**HMA**) have been prepared with equivalent design criteria.

i. **Preparation of mixtures**:

The aggregate has been dried to constant weight at 110 ^{o}C, separated into the desired size and recombined with the mineral filler in order to meet the desired gradation. The aggregate is then heated to a temperature of 155^{o}C before mixing with asphalt cement.

The asphalt cement is heated to a temperature of 160^{o}C producing a kinematic viscosity of (170 $\pm$ 20) centistokes. Then, the asphalt cements are weighted to the desired amount, added to the heated aggregate, which its gradation as job mix formula (jmf) was selected and shown in table (5) in addition to figure (1) and mixed thoroughly until all aggregate particles are coated with asphalt at optimum asphalt content (=3.98% ±0.30) of total mix.

ii. Preparation of Compressive Strength Specimens:

The test specimens, 101.6 mm (4in) diameter and 101.6 mm (4in) height are prepared after compressing initially by static stress of 1 MPa (150 psi) to set mixture against the sides of the mold, then applying a molding load of 20.3 MPa (3000 psi) for 2 mins. The specimens are ejected and oven-cured at 60^{o}C for 24 hours. The preparation is done in accordance with ASTM D 1074 specification.

3. Testing of samples:

I. Stability and plastic flow of asphalt mixtures (Marshall Method):

This method covers the measurement of stability and plastic flow of Marshall cylindrical specimens of bituminous paving mixtures loaded on the lateral surface by means of the Marshall apparatus according to ASTM D 1559. The test specimens are compacted using 75 blows on each face.

The bulk specific gravity and density (ASTM D2726), theoretical (maximum) specific gravity (ASTM D2041) and percent air voids (ASTM D3203) are determined for each specimen. The maximum load resistance and the corresponding flow values have been recorded. Three specimens for each combination are prepared and the average results are reported. Table (5) provides a summary of the volumetric properties and Marshall tests results for each of the selected mixtures.

The results in Table (6) show that crushed boulders possess more VMA values than rounded aggregate (>130%) and consequently indicate sufficient spaces with more ability to absorb access compaction under field pavement conditions. Also the results state clearly all crushed boulders mixes (in spite of their asphalt grades) have marshall stiffness value more than 150% (50% crushing) and 250% (100%) in comparison with rounded mixtures respectively, and this reality give us how the use of crushed aggregate facilitate mix to prevent rutting (permanent deformation). Table (6) indicates mixes have same flow values approximately in addition to mixes of grade (40-50) have marshall stiffness values more than 120% of (60-70) mixes.

II. Indirect Tensile Strength:

The specimens prepared in the same method and described for Marshall Method are tested for indirect tensile strength according to ASTM D 4123. The prepared specimens are cooled at room temperature for 24 hrs, immersed in a water bath at one of two different test temperatures (10 ^{o}C, and 40 ^{o}C) for 30 min., then tested for indirect tensile strength at a loading rate of 50.8 mm/min (2 in/min) in a compression machine until reaching the ultimate load resistance.

Three specimens for each mix combination are tested and the average results are reported in Table (6). The indirect tensile strength (I.T.S) is calculated, as follows:

$$[I.T.S = 2P/\pi tD] \quad (1)$$

Where: P = Ultimate applied load to fail the specimen (N), t = Thickness of specimen (mm), D = Diameter of specimen (mm).

The change in **(I.T.S)** with temperature is expressed as Temperature Susceptibility of asphalt mixture. Temperature Susceptibility for various mixes can be determined by subtracting **(I.T.S)** at 40°C from **(I.T.S)** at10°C divided by the difference between two testing temperatures as reported in Table (7).

It is observed from Table.(7), that temperature susceptibility for (40-50) mixes are less than that of (60-70) mixes, this property is due to more flexibility of (60-70) grade (more soften) under low temperature. Again, it can be concluded from table (6) the mixes of (40-50) show higher indirect tensile stiffening values under high temperatures making them more susceptible to low temperature cracking.

III. Water Damage Resistance:

This method covers measurement of the loss in cohesion resulting from the action of water on compacted bituminous mixtures. Numerical index of reduced cohesion is obtained by comparing the compressive strength of freshly molded specimens, with the compressive strength of duplicate specimens that have been immersed in water for four days at 49 ± 1 ^{o}C. The specimens of the two groups are tested in axial compression at a uniform rate of vertical deformation of 5.8 mm/min. (0.2 in/min), as recommended by ASTM D 1074. The numerical index of resistance of bituminous mixtures to the detrimental effect of water as the original strength that is retained after the immersion period is calculated in accordance with ASTM D 1075, as follows:

$$\textit{Index of retained strength} = S2/S1 * 100 \quad (2)$$

Where: S1 = Compressive strength of dry specimens **(kPa).** And S2 = Compressive strength of immersed specimens **(kPa)**.

Three specimens for each mixture combination are tested and the average value is reported in Table (8):

It can be concluded from Table (8) that the percentages of crushed boulders in each mix affects resistance of mixtures to moisture damage resistance, which is defined by index of retained strength. Results indicate that exist of crushed boulders into the mix instead of rounded type causes to increase more than 135% of index of retained strength (moisture damage resistance).

Therefore, Rounded mix has a less resistance to moisture damage {mix of (60-70) grade, has 68% less than 70% Iraqi standard value}, or in other words Rounded mix possesses a high value of moisture susceptibility, and vice versa whenever the increase of crushed boulders in the mixture leads to increase the resistance of moisture damage, this behavior return to hydrophobic property of aggregate type used in general firstly, secondly because of rough texture (toothed) of crushed boulder surfaces to build strong bond with asphalt molecules[5].

Conclusions:

From The work undertaken under the present study and described in the preceding articles, the following conclusions can be drawn:

1- Crushed boulders mixtures (Although changing the type of asphalt) have marshall stiffness value more than 150% (50% crushing) and 250% (100%)%) in comparison with rounded mixtures respectively.

2- Using of crushed aggregate instead of rounded type (> 90%) causes to increase VMA more than 130%, this means mixtures possess more durable (sufficient VA% and ability to undertake excessive compaction under heavy traffics without of asphalt bleeding).

3- In general, Mixes of grade (40-50) have marshall stiffness values more than 120% of (60-70) mixes.

4- The increase of crushed boulders in the mixture leads to increase the resistance of moisture damage more than 135%.

5- The crushed aggregate mixes show higher indirect tensile stiffening values under high temperatures in spite of possess less susceptible to low temperature cracking compared to rounded aggregate mixes.

Recommendations:

In accordance to the achieved results, therefore the SORB specifications should be revised as to use type of crushed aggregates in asphaltic mixtures (all layers) only instead of using combination of aggregates (crushed or uncrushed for both fine and coarse types) to avoid any premature failures due to this type of using**.**

Further researches:

1. Other type of crushed aggregate like lime stone can be employed to study the properties of asphalt mixtures.
2. Trial pavement sections are suggested to be prepared in the field to study the difference in performance of the various mixtures.

References

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Table (1): Physical properties of asphalt cement Penetration Grades used.

Test	Unit	Test Results	
		40-50	**50-60**
Penetration (25°C, 100g, 5 sec)ASTM D5	0.1 mm	46	57
Ductility (25°C, 5cm/min) ASTM D-113	cm	> 100	>100
Softening point (Ring & Ball) ASTM D-36	°C	53	49
Specific gravity @ 25 °C ASTM D-70		1.030	1.015
Flash point ASTM D-92	°C	>240	>240
After thin-film oven test ASTM D-1754			
Penetration of residue (25°C, 100g, 5 sec)	0.1 mm	28(>55%)	35(>55%)
Ductility of residue (25°C, 5 cm/ min)	Cm	>100	>100
Loss in weight (163 °C, 50g, 5hrs)	%	0.12	0.21

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Table (2): Physical Properties of perda quarry Aggregate**.**

Property	Rounded (river source)		Boulder crushed aggregate	
	Coarse Aggregate	**Fine Aggregate**	**Coarse Aggregate**	**Fine Aggregate**
Bulk specific gravity (ASTM C-127 & C-128)	2.612	2.612	2.687	2.685
Apparent specific gravity (ASTM C-127 & C-128)	2.695	2.695	2.741	2.732
Percent water absorption (ASTM C 127 & C-128)	0.321	0.321	0.423	0.356
Percent wear (Los-Angeles abrasion) ASTM C-131	23.8	……	12.5	…….

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Table (3): Physical Properties perda quarry crushed Aggregate.

Property	Coarse Aggregate	Fine Aggregate
Bulk specific gravity (ASTM C-127 & C-128)	2.687	2.685
Apparent specific gravity (ASTM C-127 & C-128)	2.741	2.732
Percent water absorption (ASTM C 127 & C-128)	0.243	0.356
Percent wear (Los-Angeles abrasion) ASTM C-131	12.6	-----

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Table(4): JMF Determination: Gradation Analysis Of Bitumen Base Coarse R9/3 SORB[1].

Sieve Size (mm)	Filler	0-5 mm	5-10 mm	10-20 mm	20-38 mm	Job Mix (mid)	Bitumen Base Coarse	
							Min	Max
37.5	100.0	100.0	100.0	100.0	100.0	**100.0**	100	100
25.4	100.0	100.0	100.0	100.0	60.6	**92.1**	90	100
19.1	100.0	100.0	100.0	100.0	20.0	**84.0**	76	90
12.7	100.0	100.0	100.0	58.6	6.9	**73.1**	56	80
9.5	100.0	100.0	100.0	24.2	2.3	**65.3**	48	74
4.75	100.0	92.6	29.1	2.1	0.9	**46.3**	29	59
2.36	100.0	62.4	8.8	1.4	0.8	**30.8**	19	45
0.300	100.0	21.4	2.2	0.2	0.1	**13.0**	5	17
0.075	90.0	5.0	0.6	0.2	0.1	**5.8**	2	8
Mix Ratio	4	40	16	20	20			

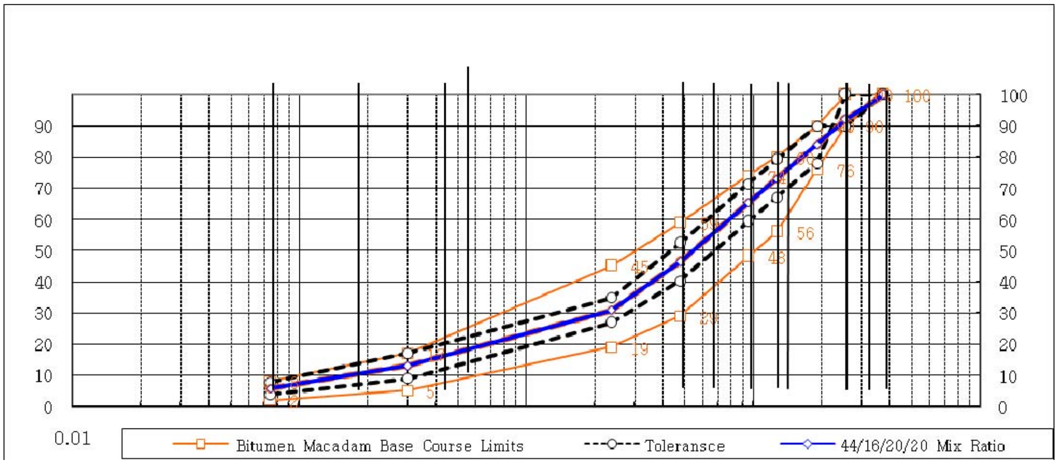

Fig.(1): Sorb Specifications And Prepared JMF Limits For Bitumen Base Coarse [1].

Table(5): Volumetric Properties and Marshall test result of Asphalt Mixtures.

Mix Property		Bulk, G g/cm^3	Theoretical. Spe. Gravity g/cm^3	Air void %	V.M.A. %	Stability kN	Flow mm	Marshall Stiffness kN/mm
Asphalt Grad	% of crushed aggregate added							
40-50	Rounded	2.350	2.422	4.01	12.45	6.95	3.2	2.172
	50%	2.340	2.423	3.9	16.34	12.34	2.90	4.255
	100%	2.341	2.431	3.87	16.76	16.90	2.80	6.036
60-70	Rounded	2.351	2.439	3.88	12.67	6,25	3.10	2.016
	50%	2.361	2.411	3.85	16.56	11.20	2.90	3.862
	100%	2.360	2.445	3.98	16.78	14.05	2.85	4.930

Table (6): Temperature Susceptibility & (I.T.S) for mixes.

Mix Property		I.T.S at testing Temperature 10°C kPa	I.T.S at testing Temperature 40°C kPa	Temperature Susceptibility kPa / °c
Asphalt Grad	% of crushed aggregate added			
40-50	Rounded	2550	380	72.334
	50%	2610	450	72.00
	100%	2670	580	69.7
60-70	Rounded	2620	280	78.00
	50%	2680	380	76.667
	100%	2740	490	75.00

Table (7): Index of Retained Strength of various mixes.

Mix property		Dry Compressive Strength(kPa)	Conditioning Compressive Strength(kPa)	Index of Retained Strength%
Asphalt Grad	% of crushed aggregate added			
40-50	Rounded	6300	4473	71
	50%	7490	6340	85
	100%	8123	7798	96
60-70	Rounded	6422	4367	68
	50%	7200	5832	81
	100%	7900	7268	92