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Effect of Aggregate Gradation on Asphalt Concrete Properties

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ABSTRACT
Economic expansion is a positive side effect of national highway construction initiatives. So, the plan is to construct these projects rapidly. This calls for premium asphalt. As a result of aggregate gradation variation, numerous asphalt mixes have been rejected and rebuilt on-site in recent decades, resulting in the waste of valuable resources and valuable time. Consequently, the goal of this study was to examine the durability of asphalt mixes where the aggregate gradation ranged from +4% above to 2% below the standard range. The aggregate gradation is inconsistent throughout HMA manufacture. The aggregate is graded at 2, 4, and 6 percent over and below the allowed range. Case in point: the gradation of the control mix design. Marshall There was a quantitative evaluation of mixed properties throughout the design phase. HMA mix performance was evaluated via high temperature and water cycles by vehicle pressure observation and Indirect Tensile Strength (ITS) testing. In hot climates, asphalt with gradations above +4% and 2% of both the higher and lower standard values showed the greatest resilience to water damage and the least rutting. In warm regions, asphalt mixture design will be constrained by the higher aggregate gradation limits.

Keywords: Asphalt Concrete, aggregate gradation, Marshall test, rutting, water resistance.

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Introduction

National highways drive economic growth and social improvement. They're essential for national growth. Access to economic, social, health, and education services makes a road network essential to poverty reduction [1]. The administration has been urged to speedily complete these tasks in order to prove its effectiveness. Due to aggregate gradation variation throughout execution and production, quick project completion hurts the final output. Asphalt pavement construction involves mixing, hauling, paving, and compaction [2]. Construction procedures have several uncontrollable aspects [[3], [4]]. Variation in asphalt design and construction characteristics has consistently caused early performance issues [5].

Thus, studying the negative effects of asphalt mix design and construction variations may be beneficial [6].

Modern pavement mixtures consist of air void, asphalt binder, coarse particles, fine aggregates, and filler [[7], [8], [9]]. A multistage compound is filled with air when aggregates and fillers are bound together with an asphalt binder [10]. Well-interlocked aggregates make for good pavement performance [11]. Asphalt mixture gradation affects pavement quality and performance [12]. Asphalt grade variation causes much pavement distress [13].

Due to aggregate gradation variance, many asphalt mixtures are rejected and repaired on-site, wasting materials, time, and money [14]. This study evaluates the feasibility of adopting mixes with aggregate gradation variation (between +4% above the higher specification limit and -2% below the lower specification limit).

Much research on the influence of gradation variation on HMA characteristics, or rather the effect of gradation variance that may occur during production on HMA properties, has been conducted in the past, according to the pavement design and construction literature [[15], [16], [17], [18], [19], [20]].

How to aggregate gradation in pavement mixes affects a massive amount of capacity and rutting resilience is the subject of research [15]. Aggregates retained on sieve sizes of 1.18, 0.6, and 0.3 mm were shown to contribute more than 50% to strength attributes, whereas aggregates retained on sieve sizes of 2.36 and 4.75 mm contributed more than 50% to resistance to weight and rutting. The clogging properties of porous asphalt mixtures as a function of aggregate gradation were investigated [16]. This study found that a mixture of porosity and pavement with pore macrotexture depth before and after blockage were both substantially connected with aggregate gradation. Also, [17] investigated the aggregate qualities effect on pavement mixture stripping and creeping deformation with the result that basalt aggregate-prepared HMA specimens resist creep better than limestone aggregate-prepared HMA specimens that have not been conditioned. Mixtures made with basalt aggregate were less resistant to creep strain after conditioning compared to those made with limestone aggregate. It was found that stripping resistance is proportional to the amount of asphalt that was absorbed. Furthermore, mixtures created with aggregate that met the upper limit of dense aggregate gradation established by the American Society for Testing and Materials (ASTM) demonstrated the strongest resistance to stripping. According to research [18], Asphalt Concrete (AC) mixture rutting and fatigue resistance can be greatly improved by utilizing different gradation sizes of aggregate and with types of additives such as fibers. Another research says that [19], gradation heterogeneity has a significant impact on pavement performance.

Research [20] suggested altering the particle fraction passing the 4.75 mm sieve screen to reduce asphalt pavement rutting. Also [21] investigated how aggregate gradation variation affected asphalt mixture rutting and found that it helped pavement withstand permanent deformation. Scientists [22] examined how aggregate gradations at construction affected to pavement performances and found that rutting tolerance increased initially and then reduced as the gradation changed from fine to coarse. Researchers tested asphalt mixes with diatomite powder and lignin fiber. The compound blend of diatomite powder and lignin fiber improved asphalt mix performance more than either alone. Combinations with lower limit gradations nearly affected HMA characteristics the most. Asphalt mixtures downwardly diverted to a lower limit grade performed best.

Thus, the aggregate gradations change in HMA is the subject of this study. So far, there hasn't been much investigation into the optimal range of aggregate gradational deviations from specification limits for HMA mixture performance. So, the purpose of this research was to examine how well HMA blends performed when aggregate gradation was outside the specified range.

The major objectives of this study are to determine the range of aggregate gradation curve specifications outside of which HMA mixture performance is not negatively affected. Next, the HMA combinations made by them will be tested for their characteristics.

Vehicle monitoring with indirect tensile strength experiments would be used to evaluate the effectiveness of the control mix to the best HMA mix that is either above or below the upper or lower specification limit. Moreover, choose the best HMA blend for the skeleton, which is resistant to both high- and low-temperature rutting strain and thermal cracking.

Methods and Experiments

Materials

The 4.75 mm (No. 4) sieve was used to separate coarse and fine aggregates, with particles being retained or passed. Meanwhile, fillers were aggregate particles smaller than the No. 200 sieve (0.075 mm). All the aggregate types were consistently graded and met the allowed range for grades defined by the local technical specifications. Coarse dolomite of both the (I) and (II) grades, whose physical properties are summarized in Table 1, was also used. Asphalt concrete was made using fine siliceous sand (bulk specific gravity 2.65 g/cm3) and limestone dust (bulk specific gravity 2.85 g/cm3). The asphalt binder properties result from the traditional way of testing presented below in Table2.

Table 1 - Coarse Aggregate Properties

No.	Name of Test	Standard	Values		Specification Limits
			Type 1 (Grade I)	Type 1 (Grade II)	
1	The Bulk specific gravity (gm/cm^3)	AASHTO T-85	2.53	2.51	N/A
	The Saturated surface dry specific gravity (gm/cm^3)		2.57	2.55	
	The Apparent specific gravity (gm/cm^3)		2.71	2.69	
2	Absorption %	AASHTO T-85	2.56	2.62	≤5
3	LA Abrasion %	AASHTO T-96	20.1	22.3	≤40
4	Stripping Test %	AASHTO T-182	>95	>95	>95

Table 2 - Asphalt Binder Properties

No.	Name of Test	Standard	Values	Specification Limits
1	A penetration test (0.1 mm)	AASHTO T-49	72	70-100
2	Softening Point (^{o}C)	AASHTO T-53	47.6	>46
3	Flash Point (^{o}C)	AASHTO T-48	+230	+220
4	Kinematics viscosity (cSt)	AASHTO T-201	341	+300
5	Ductility (cm)	AASHTO T-51	+100	>95

Table 3 - Asphalt Concrete Mixes Different Gradations

Sieve Sizes	Asphalt Concrete Mixes							Limits
	G0	G1	G2	G3	G4	G5	G6	
25.0	100	100	100	100	98	96	94	100-100
19.0	100	100	100	100	98	96	94	100-100
12.5	85	100	100	100	74	72	69	75-100
9.5	73	100	100	100	59	58	55	60-85
4.75	48	66	77	88	34	33	32	35-55
2.36	29	42	49	56	20	19	18	20-35
0.600	18	26	31	35	10	9	9	10-22
0.300	11	19	22	26	6	5	5	6-16
0.150	8	14	17	19	4	3	3	4-12
0.075	5	10	11	13	2	2	2	2-8

Gradations

According to these findings, the optimal ratio of coarse aggregates for a wearing surface is 30 percent grade I, 20 percent grade II, 15 percent natural sand, 30 percent crushed sand, and 5 percent limestone dust. Table 3 displays the intended gradation of the control asphalt concrete mixture. (G0). To emphasize the several steps in the creation of asphalt, the aggregate gradation in the mixture was made to go (1) below the minimum requirements for wearing surfaces and (2) over the maximum requirements for wearing surfaces. For the first combination (G1), the percentage of variation beyond the specified upper limit was 2%; for the second and third mixes (G2 and G3), the values were 4% and 6%, respectively (G3). In contrast, G4, G5, and G6 were assigned to the three combinations that fell between 2% and 6% below the lower standard limit.

For the first step, after materials have been chosen, we'll conduct five aggregate characterization tests, including the LA abrasions, stripping values, specific gravities, water absorptions, and design gradation selections, to ensure that stones will be in direct touch with one another.

In addition, the binder will be evaluated for its ability to penetrate, soften, flash, have a high viscosity, and be ductile.

In the second step, we produced and prepared the controlling asphalt mix (G0) as well as the other five pavement mixtures (G2 to G6) in accordance with specifications [16]. The influence of aggregate gradation variation on HMA characteristics was investigated in the third stage using the Marshall Mix Design Method.

On the G0, indirect tensile strength testing and wheel load monitoring was also performed, and samples were selected from the best mixtures that have been above and below the maximum and lower standard values, respectively.

Testing by Marshall Method

Measurements of stability (in kilograms) and flow values (in millimeters) were taken for each mix using a Marshall instrument, a Marshall machine type TO-550-1 imported from the United States to evaluate the asphalt mixes' resistance to plastic flow. The term "electronic commerce" refers to the sale of electronic goods. The compacted specimens were heated after 24 hours in a water bath at 60^{o}C 30 minutes before starting of Marshall Test. The AASHTO T-245, 75-blow Marshall Compaction test criterion was applied. During the Marshall test's stability phase, samples were initially weighed in the air before being submerged in water and then reweighed, and the greater of the two loads (in kilograms) was considered the stability value. It should be noted that correction factors were imposed for sample thicknesses more than 6 cm. The flow value, on the other hand, was determined by tracking the amount of strain placed on the specimens at their maximum load.

Wheel Loading Tracking Test

The rutting depth test is conducted by a 20-4000 Wheel track testing machine which is designed to test asphalt concrete for rutting resistance in air and in water. The unit is compatible with asphalt samples obtained on a sector press or in the form of samples. Simultaneously two samples can be tested and there are several mould configurations have been developed for testing: 320x260 mm; 340x280 mm; 300x300 mm; 410x260 mm; 400x300 mm, but for tests, the diameter of the sample must be - 150 mm in 2 pieces. Overall testing procedure programs were set according to EN 12697-22. First, the samples were prepared on a 300x300 mm mold in a special sector compactor, which is designed for the preparation of compacted asphalt samples 320 x 260 mm (410 x 260 mm optional) with a height of 40-120 mm in accordance with EN12697/33, Part 5.2. Thereby the samples were prepared approximately in 10 min, with 300x300 mm and 50 mm height to save on material. After the compactor, samples were cooled at room temperature for not less than 24 hours, subsequently, tested for 20000 passage by 2 samples in parallel in 9 hours. The received results are assumed as high temperature and intensive movement rutting resistance indicators, which meet the standard.

Indirect Tensile Strength

The AASHTO T-283 test method was utilized in order to determine the tensile properties of bitumen mixtures. In order to achieve uniform stress, this method relied on a steady pace of loading the Marshall specimen using its diametric plan. In this experiment, duplicate samples of each combination were prepared for testing. They were the "control" mixture, and "best" mixtures above and below the upper and lower specification limits, respectively. The temperature of the water was kept at 60 degrees Celsius during the conditioning process, which took 24 hours. The other set of specimens was not conditioned in any way. The term "Tensile Strength Ratio" refers to the comparison that was made between the conditioned samples' averaged indirect tensile strength and the specimens' averaged indirect tensile strength that had not been conditioned (TSR).

Results

Marshall Test Results

Each blend's OAC was determined using the Marshall Test, as indicated in Table 4. After that, we assess how well the controlled combination and other mixes at different gradation lines perform. Gradational differences showed a range of

Table 4 - Variation in aggregate gradation has an effect on the investigated blends.

AC Properties	G0	G1	G2	G3	G4	G5	G6	Limits
Optimal AC %	4.7	4.5	4.2	3.7	5.2	5.5	5.7	3-6%
Stability (Kg)	1211	1197	1182	998	1316	1325	1341	900 kg (min)
Flow (mm)	3.3	4.1	3.7	5.3	2.9	1.9	1.7	2-4 mm
Stiffness (kg/mm)	384	299	334	210	481	698	842	300-500 kg/mm
Bulk specific gravity (gm/cm^3)	2.352	2.361	2.372	2.360	2.314	2.271	2.254	-
AC Air Voids %	3.54	4.35	4.22	6.0	4.44	5.92	7.66	3-5%
VMA %	16.44	15.8	15.43	15.39	18.3	19.96	20.84	-
VFA %	87.5	72.5	72.7	61.4	75.7	65.3	63.2	-

viewpoints on the subject of aggregate gradation shifts throughout the pavement production process. These various gradation lines were seen in the G0 combinations all the way up to the G6 mixtures, as shown in Fig 1. The gradation curve design employed a combination denoted by G0 (control mix). Displayed combinations in G1, G2, and G3 were +2%, +4%, and +6%, respectively, over the maximum specification limit.

G4, G5, and G6 showed the applied mixes were -2%, -4%, and -6% below the standard lower limit, respectively. The preceding G0 through G6 mixes vary at the OAC. Each blend was evaluated according to the Marshall characteristics that are shown in Table 4. They consist of characteristics such as solidity, mobility, bulk-specific gravity, air voids, mineral voids, and asphalt voids, among other characteristics. Following the completion of the data collection process, it was analyzed.

According to the findings in Table 4, the increase in the maximum specification limits for aggregates causes a reduction in the combination's overall stability. The G0 stability value for the standard sample was calculated to be 1211 kg. The stability of the mixture was generally unaffected by two successive blends (G1 and G2), although having gradation changes that were 2% and 4% higher than the maximum standard limits, respectively. These blends resulted in declines of 1.17 and 2.4%. In the succeeding mix, gradual increments of +6% beyond the maximum specification limit led to a 17.6% loss in mix stability, reaching a low of 998 kg (G3). Nonetheless, despite this, it was still over the minimal stability level of 900 kg.

The Flow value of G0 was measured at 3.30 mm, which is greater than the permitted range of values. The flow was raised by 12.1% and 24% for the succeeding two mixes (G1 and G2) despite the fact that increasing the gradational changes by the maximum specification limit of 2% and 4%, respectively, did not prevent them from meeting the criteria (2 mm Flow 4 mm). Due to the fact that the (G3 flow) was more than the suggested threshold (5.3 mm). The values of blend consistency that is lower than the criterion are shown in Table 4. The gradations variation was less than the lower standard limit by -2%, -4%, and -6%, respectively, which resulted in the stability values of 1316 kg, 1325 kg, and 1341 kg being achieved for the aforementioned three combinations. These results may be broken down as follows: (G4, G5, and G6).

The flow numbers in Table 4 illustrate that the mixtures do not meet the requirements. The flow was observed at 3.3 millimeters when G0 was evaluated. The flow rate was reduced to 2.9 mm while using the G4 blend; nevertheless, this was still an improvement over the flow rate of 0 mm that was achieved with the previous blend. This was because the minimum value of the scale had been lowered by 2% in order to account for this change. (2 mm). This amount caused a 12.1% decrease in flow when compared to the mix that was used as the baseline. (G0). Both the G5 and the G6 mixes had a flow rate that exceeded the allowable 4 millimeters.

Wheel Loading Tracking Test Results

Table 4 shows that none of the mixes met the standard for flow and stiffness, so only G0, G2, and G4 were selected for performance evaluation tests. Furthermore, G2 was the top refracted mixture up of the lower permitted limits for mixtures gradations that obey the standard requirements, while G4 was the highest diffracted mixture below it (wheel load tracking and indirect tensile test). Easily distinguishing the gradation lines in comparison to the G0 control mixture is seen in Figure 1.

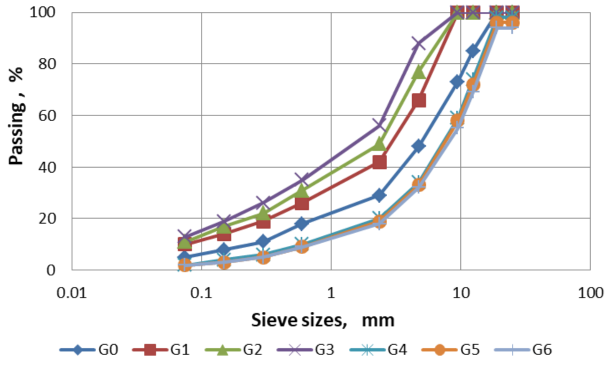

Figure 1 – Gradation lines of the mixes

Figure 2 shows the rutting depth test results for the 3 mixtures: G0 (Control), G2 (the best mixture, which is +4% over the higher specification limit), and G4 (the best mix, which is -2% below the lower specification limit). Figure 2 shows that the rutting value for the G0 mix is 3.92 mm, 4.85 mm for the G2 mix, and 4.34 mm for the G4 mix. The G2 increased its rutting depth by 18% over the G0 and 9.5% over the G4. This means that compared to mix G2, mix G4 showed a greater rutting resistance. It is related to an 11.1% improvement in stability and a 30% decrease in flow for G4 when compared to G2.

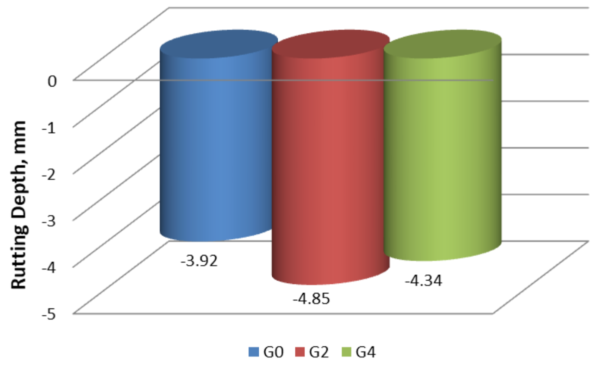

Figure 2 - Rutting Depth Results

Tensile Strength Test Results (Indirect)

TSR results for three different permutations are shown in Figure. 3. According to the same source, Mix G2 achieved a remarkable TSR of 81.62%, whereas the TSR of the G0 control Mixture was 83.87%. When compared to the G0 control mix, this indicates a decrease in TSR of 2.7%. Figure 3 also reveals that G4 had a TSR of 82.84%, which is somewhat higher than G2's 82.65%. The most important takeaway from this study is that G4 is more resistant to moisture-induced damage when compared to G2 in a combination.

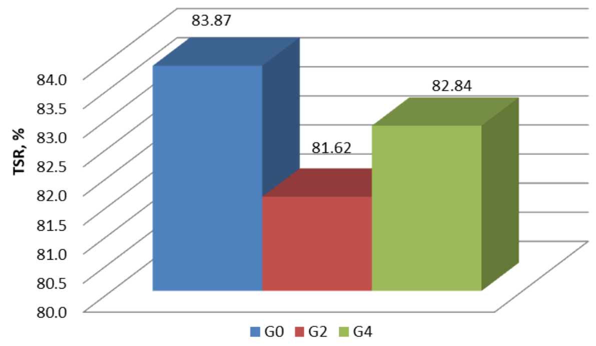

Figure 3 - TSR Outcomes

According to the results G2 and G4 mixes were more moisture resistant than the Control Asphalt Mixture. The fineness of its stone matrix increased cohesiveness between the matrix and the low asphalt component, which was harmed by the water path's high temperature. The asphalt mixes' anti-shear strength, rutting, and tensile strength rose as asphalt mastic and aggregate adhesion increased. Based on this debate, the mix at 2% below the lower gradation limit performed better against moisture-induced damage than the one at +4% above.

The results showed that compared to the Control Mixture G0, G2, and G4 had improved resistance to moisture damage. The fineness of aggregate fractions may have increased the cohesiveness between the matrix and the low asphalt component, making it more susceptible to the negative effects of the hotter water in the water route. Thus, the tensile strength of asphalt mixes improved, and the anti-shear strength and rutting of asphalt mixes were enhanced by the increased adhesive force between asphalt mastic and aggregate.

Conclusions

This research proposed a unique aggregate gradation variation of 2%, 4%, and 6% from aggregate specification limitations. After laboratory preparation and testing, wheel loading tracking, Marshall method test, and (ITS) Indirect Tensile Strength test was used to measure HMA characteristics at high-temperature performances, various asphalt blends, and their resistance to water. This is what the data seems to indicate.

G2 and G4 considerably improve asphalt mix performance. G2 mix improves water stability but not rutting resistance. G4 mixture boosts strong performance at high temperatures and resistance to water damage. G4 outperformed G2 in rutting resistance. G4 was more moisture-resistant than G2. Overall, mix G4 improves pavement service life and ride quality more than mix G2.

Conflict of interest. On behalf of all the authors, the correspondent author states that there is no conflict of interest.

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Толтырғыш градациясының асфальтбетон қасиеттеріне әсері

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ТҮЙІНДЕМЕ
Ұлттық жол құрылысы жобалары экономикалық өсуді ынталандыратын ұлттық табысқа әсер етеді. Осылайша, шешім қабылдаушылар бұл жобаларды тез құруы үшін жоғары сапалы асфальт қажеттігін ескерді. Соңғы он жылдықтардағы басты мәселе – көптеген асфальт-бетон қоспалары қайта өңделіп, шикізаттың, шығындардың және уақыттың жоғалуына әкелетін толтырғыш градациясының айырмашылығына байланысты деген шешімге тірелді. Бұл зерттеуде агрегаттың градациясы талаптың жоғарғы шегінен +4% - дан спецификацияның төменгі шегі -2% - ға дейін өзгеретін асфальт қоспаларының жарамдылығы қарастырылады. Ыстық асфальт қоспасын (ЫАҚ) өндіруде толтырғыштың градациясы спецификациядан асып түседі. Толтырғыштардың градациясы белгіленген шектерден 2%, 4% және 6% жоғары және төмен алынатын болады. Бақылау жағдайы: бақылау қоспасының гранулометриялық құрамы. Marshall Mix жобасы бойынша жасалып қоспаның қасиеттері өлшенеді. Жоғары температура мен су циклдері кезінде ЫАҚ-ның өнімділігін бағалау үшін доңғалақ жүктемесін бақылау және жанама созылу беріктігін сынау (ITS) қолданылды. Спецификацияның жоғарғы және төменгі шегінің +4%-дан -2%-ға дейінгі градациясы бар қоспалар стандартты асфальт қоспаларымен салыстырғанда, ең аз дөңгелек ізінің тереңдігіне және ыстық жерлерде судың әсерінен бұзылуына барынша төзімділікке ие болды.Толтырғыш градациясының жоғарылауы ыстық климатта асфальтбетон қоспаларын жобалау кезінде нұсқаулық болады.
Түйін сөздер: асфальтобетон, тас градациясы, маршалл тест, дөңгелек ізі, ылғалға төзімділік.

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Влияние градации заполнителя на свойства асфальтобетона

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АННОТАЦИЯ

Проекты строительства национальных дорог влияют на национальный доход, что стимулирует экономический рост. Таким образом, лица, принимающие решения, намерены строить эти проекты быстро. Для этого требуется высококачественный асфальт. Основной проблемой последних десятилетий является то, что многие асфальтобетонные смеси отбраковываются и переделываются на месте из-за разницы в градации заполнителя, что приводит к потере сырья, затрат и времени. Таким образом, в данном исследовании рассматривается приемлемость асфальтовых смесей с изменением градации заполнителя от +4% выше верхнего предела спецификации до -2% ниже нижнего предела спецификации. При производстве горячей асфальтовой смеси (ГАС) градация заполнителя выходит за рамки спецификации. Градации заполнителей на 2%, 4% и 6% выше и ниже установленных пределов. Контрольный случай: гранулометрический состав контрольной смеси. Измеренные качества смеси по проекту Marshall Mix. Для оценки характеристик смеси HMA при высоких температурах и водных циклах использовались мониторинг нагрузки на колеса и испытания на непрямую прочность при растяжении (ITS). Смеси с градацией от +4% до -2% от верхнего и нижнего пределов спецификации имели наименьшую глубину колейности и максимальную устойчивость к разрушению водой в горячих местах по сравнению со стандартными асфальтобетонными смесями. Повышенные ограничения по градации заполнителя будут служить руководством при проектировании асфальтобетонных смесей в жарком климате.

Ключевые слова: асфальтобетон, градация заполнителя, испытание Маршалла, колейность, водонепроницаемость.

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