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Effect of water flow within the surface HMA layer on Performance

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Abstract

One of the main causes of early failure of paving is water flow within its surface layers. In this study, a new experimental work has been proposed to increase the permeability coefficient using two specifications aggregates (G_1 and G_2) and to increase the coarse gradient ratios subjected to the scrb2003 limits. This enables the angularity of aggregates to maintain coherence and to ensure acceptable stability characteristics. In order to accomplish this purpose, several models have been prepared to study the effect of increasing proportions of coarse aggregate on the properties and whether they serve the desired purpose. The results showed an increase in the stability of G_2 in general in contrast with the results of G_1. The permeability coefficient also increased for G_2 mixtures by 0.005. Indirect tensile testing demonstrated an increase in T.S.R of 10.5% for the specification of G_2.

Keywords*:* Permeability coefficient, Grading of aggregate, Pavement voids, Hot mix Asphalt Water flow.

1.Introduction

The hydraulic properties of the surface layer mixture are extremely important because they are to blame for many of the problems it has.The hydraulic properties of permeable friction course and common tests used to characterize them are discussed in this paper. The capacity of a substance to transport fluids is measured by its permeability. The literature involves a broad range of measured values for permeability, hydraulic conductivity, and infiltration rate. Despite the fact that these parameters are often used interchangeably, they do not refer to the same property. The permeability coefficient that connects volumetric flux and hydraulic conductivity is called hydraulic conductivity. Many of the test methods have one thing in common that all use a dropping head apparatus to determine the pavement's flow capability. The test records amount of time taken for a certain amount of water to drain into the pavement, which can then be converted to a flow rate calculation [1].

Bear [2] described the commonly used methods for determining the hydraulic conductivity of porous media. The measurements included a flow meter to determine whether a flow is unsteady or steady in the vertical or horizontal direction through a cylindrical specimen. The word permeameter is used to explain how permeable material.

Ruiz et al. [3] conducted a study on porous asphalt mixtures. They measured the time taken to drain 1.735 l of water using a LCS Drainometer. To keep the water from surfacing, a large plate is placed across the tube’s rim. They developed an equation

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using laboratory experiments to relate the drainage time (T) with percent of void content (H).

Regimand and colleagues [4] invented a system for measuring the amount of air voids in compressed materials. This procedure determines a porous sample's effective air void (EAV) material, which is a subset of the total void content. The EAV content includes voids that are accessible to water and other environmental fluids, but none that are accessible to liquid during the compacted materials use. Since it has a close relationship with mixture permeability, the EAV parameter is useful.

Tan et al. [5] examined porous asphalt drainage properties in order to assess surface course design criteria. The efficiency is determined by the asphalt's properties as well as the roadway's longitudinal gradient and cross-slope. The porous overlay must be engineered with the various properties in mind since water flows inside the porous asphalt structure . The minimum thickness requirement, in particular, must be substantial enough to prevent sheet flow on the pavement, which would mitigate the safety benefits during rainstorms. Tan et al. used specify the software to model a porous asphalt roadway. According to the researchers, the cross slope, longitudinal slope, pavement thickness, and width all had a substantial effect on drainage quality. They were able to plot the relationship between rainfall intensity and the necessary asphalt thickness per pavement.

Anderson et al. [6] studied the cross and longitudinal slopes impact drainage capacity and concluded that during a rainstorm, the thinner the water film, the higher the skid resistance and reduction in hydroplaning potential.

For porous pavements, Ranieri [7] created a model that can be used to decide the minimum design thickness by comparing the hydraulic conductivity to the geometric characteristics of the roadway and the rainfall rate. Moreover, the model calculates the depth of water flowing in the pavement. Ranieri concluded that the porosity and inclination of the impervious base affect the drainage ability. In order to mitigate surface runoff, Ranieri developed a map that can be used to measure thickness of a pavement After that, Ranieri concluded from another published paper that the hydraulic conductivity of porous materials varies depending on the flow regime of the draining water. The drainage potential of permeable frictioncourses (PFC) is found to be proportional to its thickness in a linear fashion. Pavement slope, rainfall rate, permeability, and thickness are all variables in Ranieri's design equations [8]. Zwan et al. [9] investigated the use of porous asphalt in the Netherlands, where it was first used 30 years ago, due to the large amount of precipitation received during the year. They used a thicker regular thickness of 50 mm to store a lot of water in case of a flood.

The aims of this study were to (1) investigate the physical properties of hot asphalt mixtures, (2) investigate the impact of aggregate gradation in the surface layer on mixture filtration, and (3) assess the permeability of the dense asphalt mixture.

2. Methodology and Materials

2.1 Asphalt Cement

The asphalt cement used was within (40-50) penetration grade and brought from Al-Durah refineries. The physical properties and tests of the asphalt cement used are shown in Table 1.

Table 1. Physical properties of the asphalt cement.

Property	Test Condition and units	ASTM Designation	Test Value	Standard Limit according to SCRB/R9,2003
Penetration	25C°, 100 gm, 5 sec. (0.1mm)	ASTMD5, 2006	43.23	40-50
	46 C° ,50 gm, 5 sec		253.6	
	4 C° ,200gm, 60 sec		76.7	
Rotation Viscosity	Pa.s	ASTM-D4402	0.54@135°C	
			0.15@165°C	
Softening Point	60 C°	ASTMD36, 1995	51	-
Ductility	25 C° ,5cm/min	D113-99	150 cm	>100 cm
Specific Gravity	25 C°	D70-97	1.032	-
flash Point	C°	(ASTMD92, 2005)	240	>232
Fire Point	C°	D92-05	295	>232

2.2 Aggregate

This study focused on studying the effect of using different gradients in the surface layer of paving on mixture filtration, then studying their effects on permeability and water seepage. The physical properties of aggregates shown in Table 2 were natural crushed aggregate (available locally site) with maximum size of 9.5 mm used for all mixes as suitable for surface layer of flexible pavement (SORB/R9) [10]. Two aggregate gradations used in this study are shown in Table 3 (shaded by green color) and Fig. 1.

Table 2. Physical properties of aggregates

Property	ASTM Designation	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127	2.5	2.54
	C-128		
Apparent Specific Gravity	C-127	2.56	2.6
	C-128		
% Water Absorption	C-127	0.67%	0.81%
	C-128		
%Wear (Los Angeles)	C-131	25%	
		Max 35%	-
Degree of Fractional	D 5821	95%	-

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Table 3. Gradations of aggregates used for Surface Layer.

Sieve size	% Passing		scrb2003	
	Gradations No.1 (G_1)	Gradations No.2 (G_2)	Min	Max
12.5	100	100		100
9.5	90	95	90	100
4.75	60	70	55	85
2.36	34	34	22	67
1.18	24	23		
0.6	16	16		
0.3	11	11	7	23
0.075	7	7	4	10

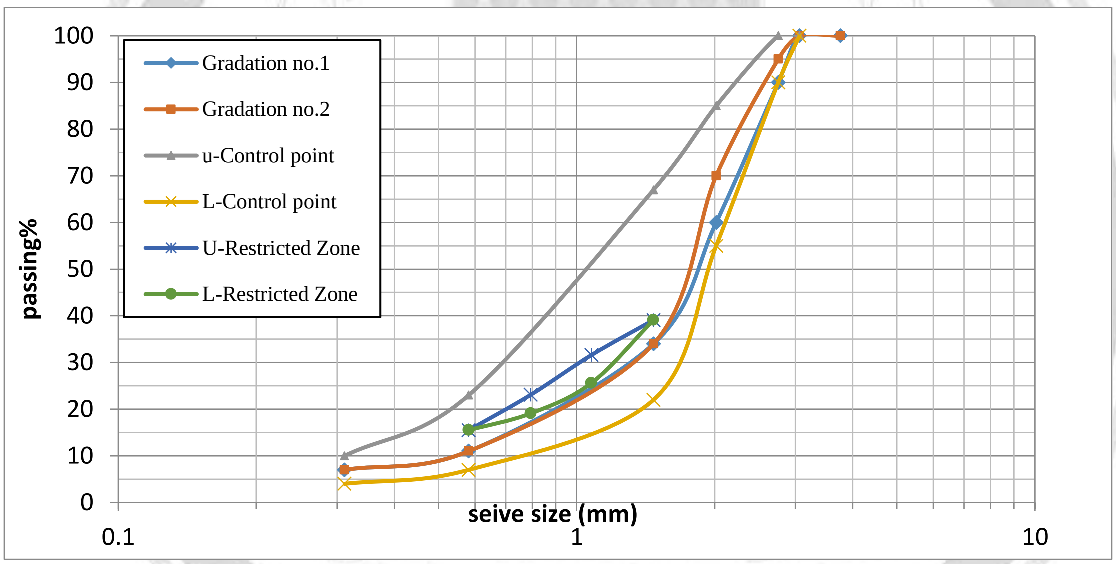

Figure 1. Trail Gradations for Surface Layer.

2.3 Experimental Procedures

The process of designing the asphalt mixture began after preparing the raw materials needed for it, executing the appropriate inspections for it, and confirming that it corresponded to the standards. The Marshallian design approach was used,where after taking the required weights from a sieves and heating it to 175 Co, heating the asphalt to 160 Co, and mixing the form quickly until the temperature drops to 140 Co.

Five asphalt ratios ranging between (4-6) % were used in preparing the mixing. Stability, vacuum and flow tests were performed to find the value of asphalt. After finding the value of asphalt, samples were prepared from the asphalt mixture with different number of strokes to study the effect of permeability and moisture.

After calculating the optimal content, models were prepared to study the effect of aggregate gradation on both permeability and moisture sensitivity. Models were established with different number of strokes, as mentioned in the following articles.

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2.3.1 Optimum Asphalt Contents (OAC)

The optimal asphalt contents (OAC) for each aggregate gradation were determined. Five percentages of asphalt content were examined to find OAC starting with 4% and ending by 6% at interval of 0.5%, consequently and samples were tested for this purpose. The samples of OAC determination were illustrated in Figure. 2. The optimum asphalt content selected for design is essentially a compromise value, which meets specified requirements for stability, flow, and Voids in Total Mix (VTM).

From experimental work in this study, the optimum asphalt content required for G1 was (4.7%) and for G2 was (5.3 %).

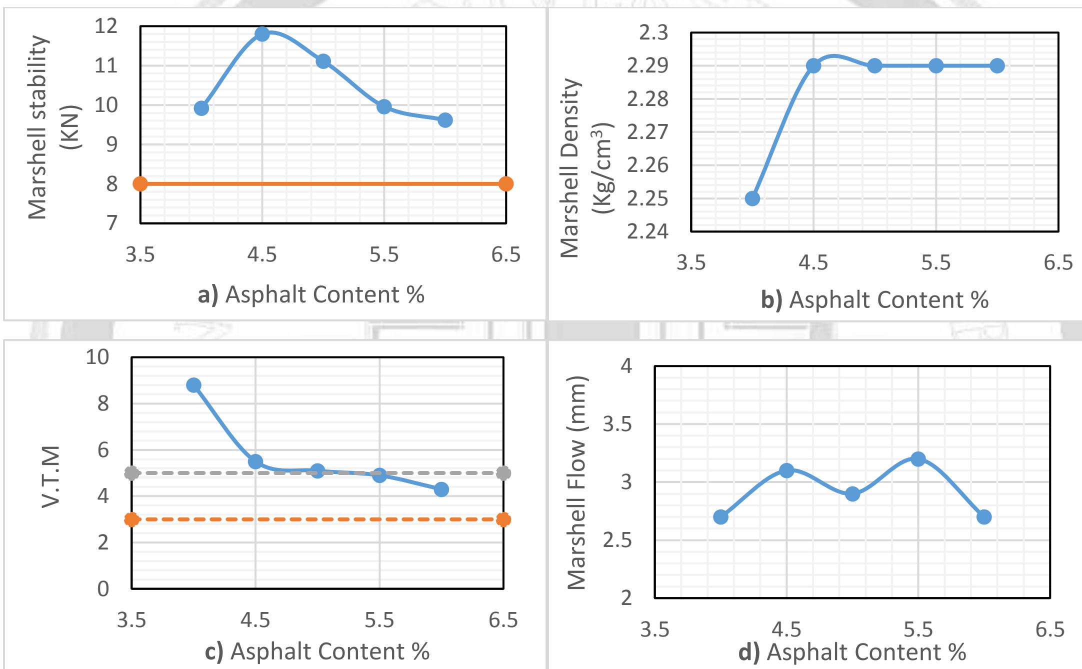

Figure 2. Determination of OAC according to Marshall method for G_1: a) Relationship between Stability and AC%; b) Relationship between Unit weight and AC%; c) Relationship between Air void and AC%; d) Relationship between Flow and AC%.

2.3.2 Laboratory Permeability Test

The general method for laboratory testing processes was developed by the Florida Department of Transportation (FDOT). ASTM PS 129-01 demonstrates this technique. Permeability of bituminous Materials, which has been adopted as the standard lab test. The FDOT and modified tests are distinguished by the fact that the FDOT used an epoxy resin to seal the core's sidewalls, while the modified test used a flexible latex membrane. This test can use a sample cut from the field, or loose mix from the plant can be formed into a core for testing [11]. The test specimen is saturated in a de-aeration chamber after it has been prepared. After that, the sample is put in a pressurized chamber to prevent water from moving through the sample's sides. After that, the standpipe is filled with water and the valve is opened. The time was reported for water level to drop from the initial to the final head value after that. To calculate the coefficient of permeability, the information from test and dimensions of the core are entered into Darcy's Law. The specimens for lab permeability testing in this study had dimensions of 4 inch diameter and 2.5 inch height, with an air void percentage of about 7% in the total mix. The coefficient of permeability, K, is determined using the following equation (1). Plate 1 represents the schematic Diagram and setup of HMA permeability test and its apparatus.

$$K = \frac{aL}{At}\ln(h_1 / h_2) \qquad (1)$$

Where:

K = coefficient of permeability, (cm/s);
a = cross section of test tube, (cm^2);
L = average thickness of the test specimen, (cm);
A = average cross-sectional area of the test specimen, (cm^2);
t = elapsed time between h_1 and h_2, (sec);
h_1 = initial head across the test specimen, (cm);
h_2 = final head across the test specimen, (cm).

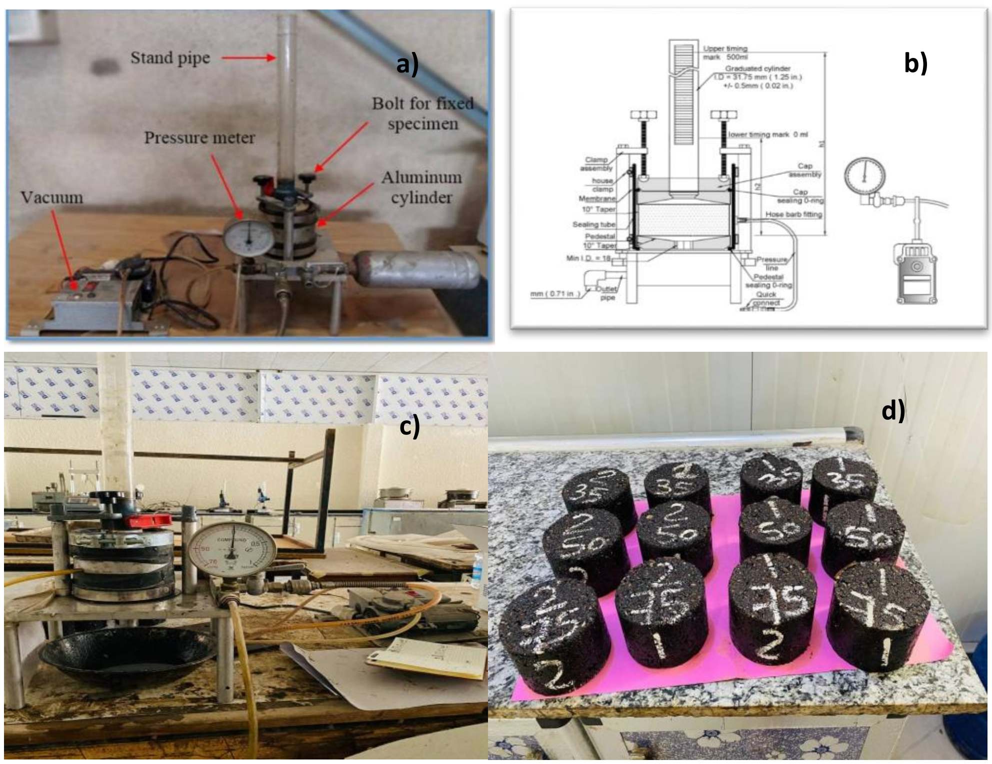

Plate 1. The schematic Diagram and setup of HMA permeability test a) The schematic Diagram of HMA permeability test (Florida Department of Transportation) b) Permeability apparatus c) Mixing Samples d) The method of checking the device.

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2.3.3 Evaluation of Moisture Sensitivity

AASHTO T 283 research on the design aggregate blend at the design asphalt binder material is used to assess the model mixture's moisture sensitivity. The density of the specimens is compressed to about 7% air voids. A subset of three specimens was considered as a control group and the rest as a conditioned subset. At 60 Co, the conditioned subset is subjected to vacuum saturation, an optional freeze time, and a 24-hours thaw cycle [12]. The indirect tensile strengths for all specimens were determined. Moreover, the moisture sensitivity is determined by dividing the tensile strengths of the conditioned subset by the tensile strengths of the control subset. The following equation is used to determine the tensile strength [12]: -

$$S_t = \frac{2000P}{\pi t D} \quad \text{.........} \quad \text{(SI units)} \qquad (2)$$

Where:
S_t = tensile strength, (kPa);
P = maximum load, (N);
t = specimen thickness, (mm);
D = specimen diameter, (mm).

The tensile strength ratio is calculated as follows according to AASHTO T 283: Tensile Strength Ratio [12]:

$$TSR = \frac{S2}{S1} \qquad (3)$$

Where:
S1= average tensile strength of the dry subset, (kPa);
S2 = average tensile strength of the conditioned subset, (kPa).

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Plate 2 shows the steps for indirect tensile testing that conducted in experimental work in this study.

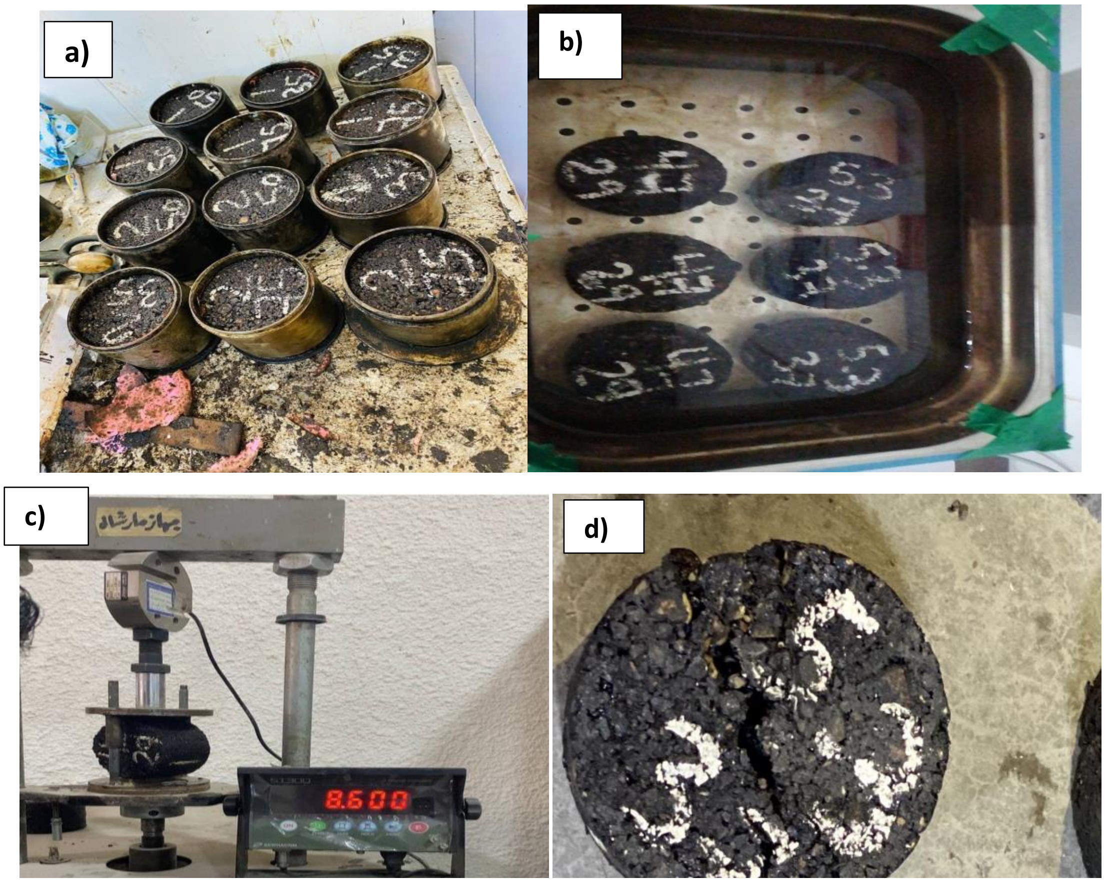
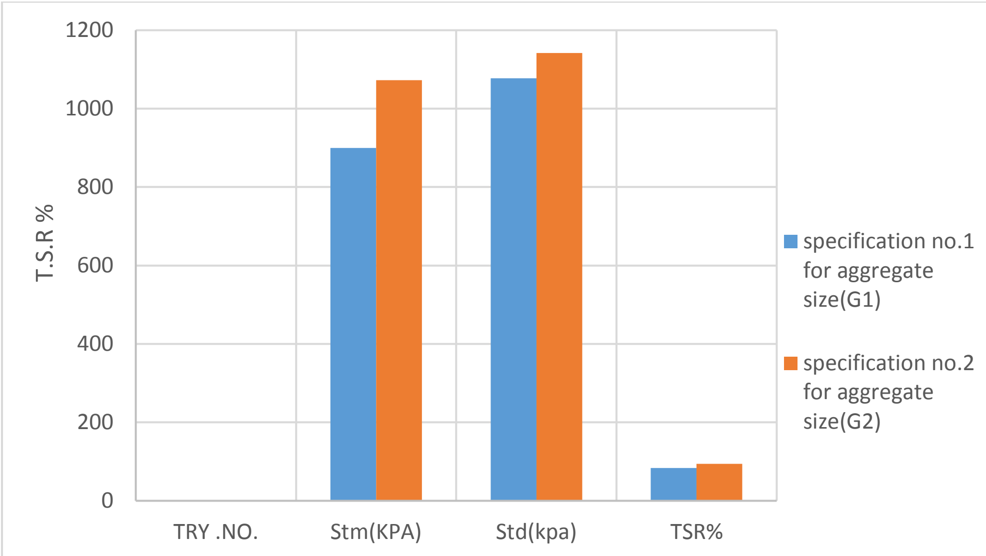


Plate 2. Steps for indirect tensile testing a) Preparing tested samples b) Treated in a water bath c) Examining the model with a tensile tester d) sample after failure.

As mentioned previously, two specifications were used for grading the aggregate of surface layer within a maximum aggregate volume of 9.5. The results of all mixtures met the requirements of AASHTO-T 283, which showed that the tensile strength ratio should be at least 80%. Indirect tensile testing observed an increase in T.S.R of 10.5% for the specification of G2. Fig. 3 shows a comparison of the results of the TSR test for the G1 and G2.

Increasing the overlap and bonding of aggregate particles to each other as well as increasing the adhesion between aggregate and asphalt, lead to a decrease in HMA stripping and horizontal deformation. However, an increase in tensile stiffness modulus values is also observed from this study.



. Figure 3. A comparison of the results of the TSR test for G1 and G2

3. Results and Discussion.

3.1 Marshall Stability.

Three specimens were tested for each aggregate gradation in the Marshall stability test. ASTM D 1559-89 was used to prepare and test the specimens. The specimens were cured in a water bath at 60 C° for 30 minutes before being tested to determine the ultimate load. Fig. 4 shows the findings of the results.

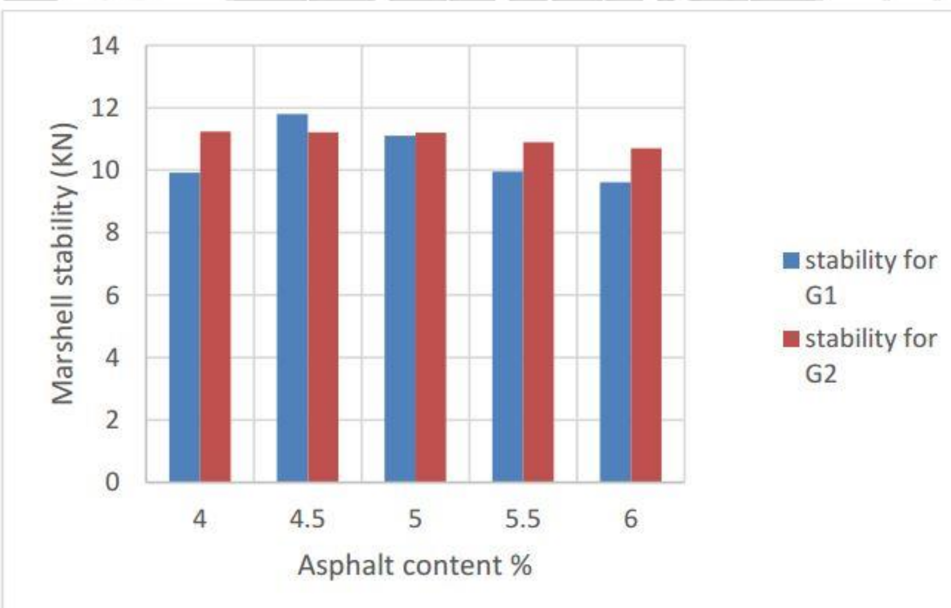


Figure 4. Test results of marshall stability.

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From Fig. 4, the highest stability obtained within an asphalt content of 4.5% was (11.8 kN) within the specification of the first gradient (G1), while the other within asphalt content of 4% the standard was (11.24 kN) on a general level. The stability increased by increasing the coarse gradients of aggregates and this may be attributed to the overlap between the rubble, which gives higher stability.

3.2 Air Voids

Because air voids allow water to flow through the asphalt, they are frequently used to characterize the permeability of a mixture. When discussing such pavement materials, however, there are many types of voids to be considered. Interconnected or isolated air voids are possible. Impermeable mixtures are those that have minimal voids and are not intertwined [13]. As a result, just because a mixture contains air voids does not mean it will be permeable. The coefficient of permeability is proportional to the available air voids [14]. The interconnected voids that allow water to flow are referred to as accessible air voids. Air voids play an important role in the longevity of asphalt pavements, specifically in shaping resistance to the action of air and water, choose air void for blending [15]. This is necessary to ensure that the key qualities of the surfacing, such as durability, moisture susceptibility, raveling, and so on, are not jeopardized. Through the practical results shown in Fig. ٥, an increase in the percentage of air void with an increase in the gradient of coarse aggregate can be noticed, which makes the permeability faster at the same time. It can be also noticed that with the increasing of the percentage of blows, less percentage of air voids can be achieved.

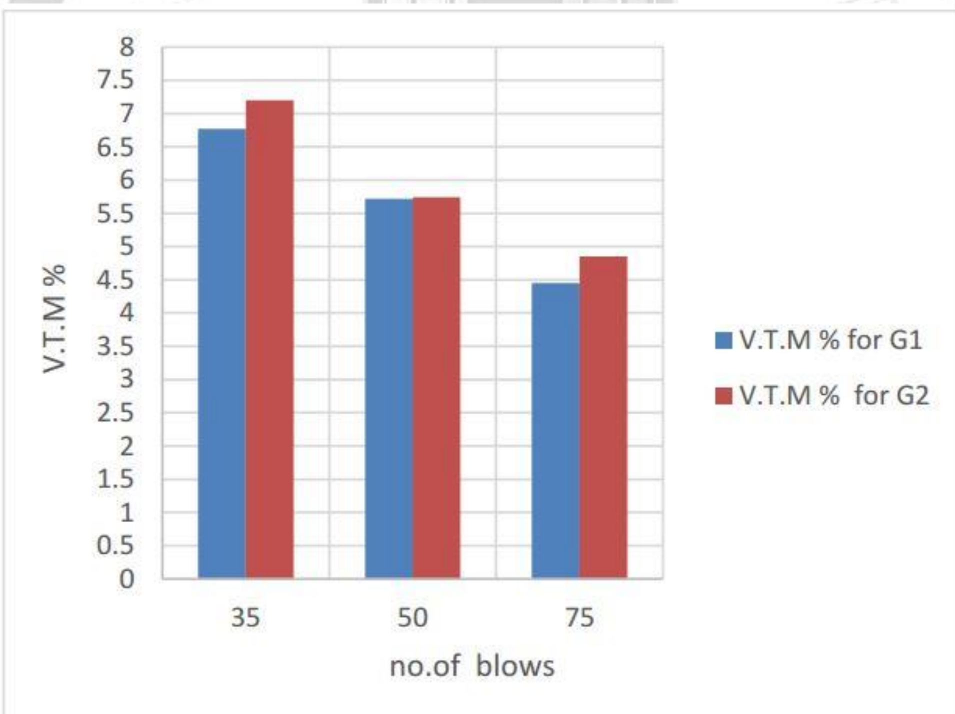

Figure 5. Test results of V.T.M %

From Fig. 5, decreasing the number of voids and increasing the limit energy due to the occurrence of the phenomenon of joining, lead to the decrease of the mixture volume. When the size of the used aggregate increases, it is difficult to join and leads to a high void ratio.

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3.3 Voids in the Mineral Aggregate (VMA)

Voids in the mineral aggregate (VMA) are the air voids that exist between the aggregate particles in a compacted paving mixture including voids filled with asphalt. The results of VMA are shown in Fig. 6.

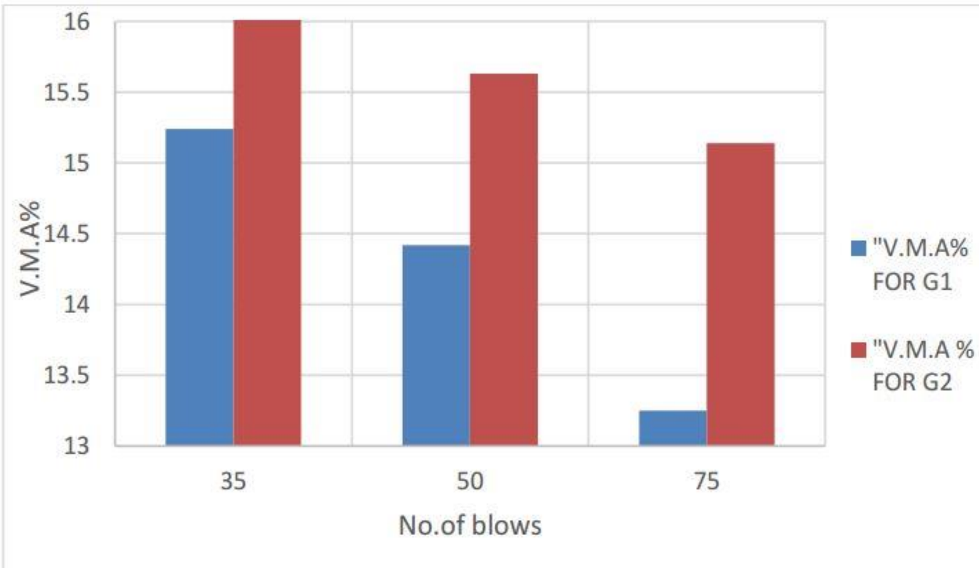

Figure 6. Test results of V.M.A %.

From Fig. 6 it is observed that increasing the V.M.A void value while increasing the coarse gradient at the same time as well as increasing the number of blows contributed to the decrease of V.M.A in the second gradient. This may be due to increased asphalt content in G2.

3.4 Bulk Specific Gravity (Gmb)

The results of bulk specific gravity of mixture are shown in Fig. 7. It can be noticed that the Gmb increasing with increased the NMAS.

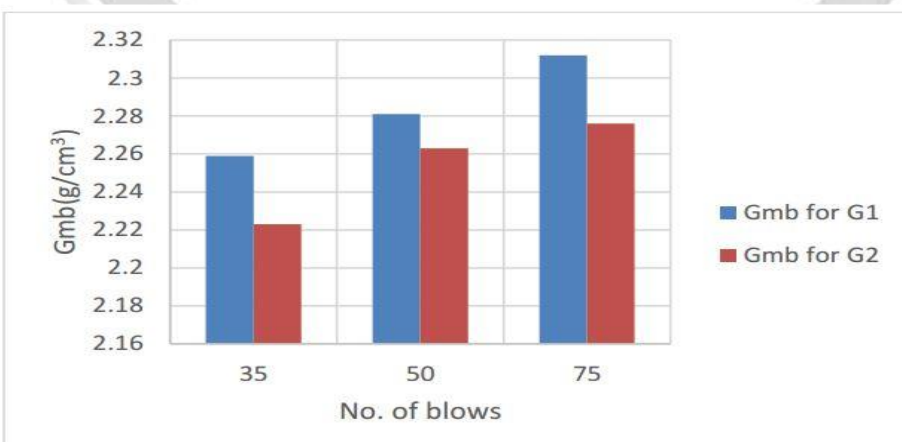

Figure 7. Test results of Gmb.

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Increasing the density of the asphalt mixture is as a result of the decrease in the percentage of voids that result from the regular bounding. Consequently, this leads to decrease the volume of mixture, which causes increasing the density (Fig. 7). The density is considerably affected by the size of aggregate used, which reduces the hook size, and thus increases the density. Moreover, for the same number of blows, the bulk specific gravity of G_1 was greater than G_2.

3.5 Permeability Coefficient

From experiment, an increase in NMAS leads to increase the permeability values. This may be attributed to large amount in coarse aggregate particles quantity and a decrease in amount of fine aggregate particles. Consequently, the interconnectedness of air voids can increase, allowing more particles to cross paths, which is true in the case of NMAS's major influence on the permeability value. The same tendency can also be observed by other researchers [16]. Fig. 8 shows a comparison of the permeability test results for the two specifications used for grading aggregates.

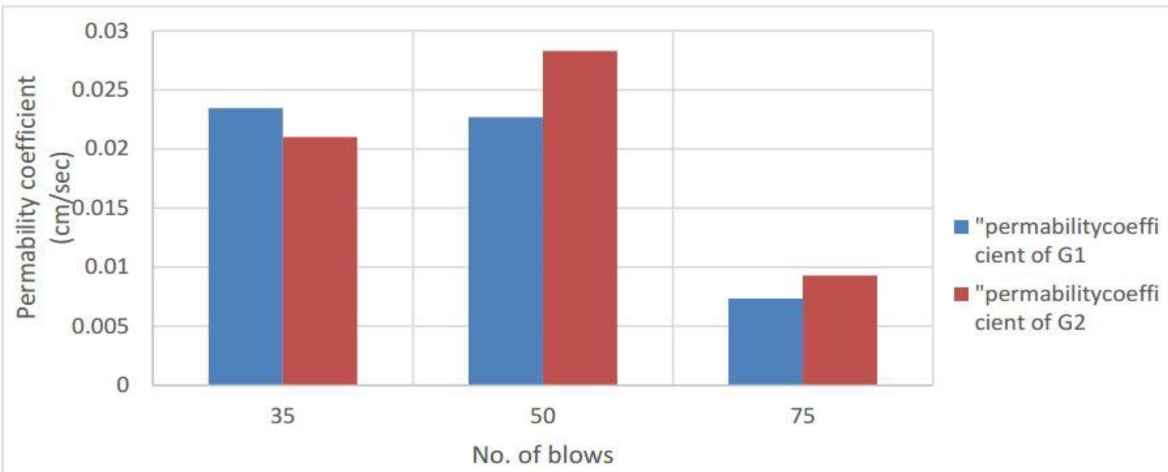

Figure 8. A comparison of the results of the permeability coefficient test for the G_1 and G_2.

The permeability coefficient increases with increasing the percentage of voids resulting from the decrease in the level of the boundary. This indicates that the irregular boundary process of the asphalt paving layers generates a high percentage of the void that allows penetration and facilitation of water movement within the asphalt mixture. The higher the coarse aggregate percentage in the mixture, the larger the void ratio generation will be (see Fig. 8).

4. Conclusions

In this study, the impact of various factors such as air voids and grading on asphalt permeability has been investigated using a new experimental work. Two specifications aggregates (G1 and G2) and an increasing the ratio of coarse gradient were used for this purpose, several models were prepared. The results show that the permeability coefficient increased with increasing the percentage of voids resulting from lowering the boundary level. The irregular boundary process of the asphalt paving layers generates a high percentage of the void that allows penetration and facilitation of water movement within the asphalt mixture.

The higher the coarse aggregate percentage in the mixture, the larger the void ratio will be. The permeability coefficient is reduced for finer mixes and increased for coarser mixes. Increasing the coarse gradation of aggregate contributes to the increase permeability, thus

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preserving the tiling from the damage caused by water if it is present in the tiling for a longer time. According to mix stability, the highest value obtained within 4.5% asphalt content was (11.8 kN) for the first gradient (G1). On the other hand, the gradation of aggregates was (11.24 kN) for asphalt content of 4%. Moreover, the mixture stability increased by increasing the coarse gradients of aggregates and this may be attributed to the overlap between the rubble and gives higher stability.

Decreasing the number of voids by increasing the limit energy due to the occurrence the phenomenon of joining leads to decrease the mixture volume and increase density. When the size of the used aggregate increases, it is difficult to join and result a high void ratio. Moreover, the density is remarkably affected by the size of the aggregate used, which reduces the hook size and thus increases the density.

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Conflict of interests.

There are non-conflicts of interest.

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تأثير تدفق الماء داخل طبقة الأسفلت ذات الخلط الساخن على أداء الرصيف

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الخلاصة

أحد الأسباب الرئيسية للفشل المبكر للرصف هو تدفق المياه داخل طبقات سطحه. في هذه الدراسة، تم اقتراح عمل تجريبي جديد لزيادة معامل النفاذية باستخدام مجموعتي مواصفات (G1 و G2) ولزيادة نسب التدرج الخشن الخاضعة لحدود scrb2003، كما ان الركام الزاوي يساعد على التماسك وضمان خصائص الاستقرار المقبولة. من أجل تحقيق هذا الغرض، تم إعداد العديد من النماذج لدراسة تأثير زيادة نسب الركام الخشن على الخصائص وما إذا كانت تخدم الغرض المطلوب. أظهرت النتائج زيادة في ثبات G2 بشكل عام على عكس نتائج G1. كما زاد معامل النفاذية لخلائط G2 بمقدار ٠,٠٠٥. أظهر اختبار الشد غير المباشر زيادة في TSR بنسبة ١٠,٥ ٪ لمواصفات G2.

الكلمات الدالة: معامل النفاذية، تصنيف الركام، فراغات الرصف، تدفق مياه الإسفلت المزيج على الساخن.