PERFORMANCE OF ASPHALT CONCRETE CONTAINING CRUSHED AND UNCRUSHED GRAVEL WITH HIGH FLAT-PARTICLE CONTENT

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ABSTRACT

The aggregate shapes affect corresponding asphalt concrete performance. Asphalt concrete composed of more cubical, angular, and coarse-textured aggregates has higher performance than the one composed of elongated, flat, rounded, and smooth aggregates. Nevertheless, the available materials might be not perfect, for example, the materials might be the gravel with high flat-particle content. These gravels commonly are crushed to form angular and coarse-textured particles; however, the post-crushing products might be flatter, although the shapes become angular and coarse. No research has been found that compares the performance of asphalt concrete containing such aggregates. The objective of this study is to compare the performance of asphalt concrete containing high flat-particle content crushed gravel and the one containing high flat-particle content uncrushed gravel, in term of Marshall stability and Marshall durability. The Marshall method was used, in which, a total of 27 samples of asphalt concrete were tested. The result shows that the stability of asphalt concrete composed of crushed gravel with high flat-particle content is 38.8% better than the one composed of uncrushed gravel with high flat-particle content. In addition, the durability of the asphalt concrete composed of the crushed aggregate is 5.6% better than the one composed of the uncrushed aggregate.

Keywords: flat gravel, crushed aggregate, Marshall stability

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ABSTRAK

Bentuk agregat mempengaruhi kinerja beton aspal. Beton aspal yang mengandung agregat yang menyerupai kubus, bersudut, dan bertekstur kasar memiliki kinerja lebih baik dibandingkan dengan beton aspal yang mengandung agregat yang relatif bulat, lonjong, pipih, dan bertekstur licin. Namun, agregat yang tersedia tidak selalu sempurna. Material yang tersedia terkadang dapat berupa kerikil dengan kandungan agregat pipih yang tinggi. Kerikil ini biasanya dipecah untuk menjadi agregat yang bersudut dan bertekstur kasar, namun setelah dipecah agregat dapat lebih pipih walaupun bentuknya bersudut dan teksturnya kasar. Sejauh ini, belum ditemukan penelitian yang membandingkan kinerja beton aspal yang mengandung kerikil dengan kandungan agregat pipih yang tinggi pada saat agregat belum dan sudah dipecah. Tujuan dari penelitian ini adalah membandingkan beton aspal yang mengandung kerikil yang dipecah dengan kepipihan yang tinggi dan beton aspal yang mengandung kerikil yang tidak dipecah juga dengan kandungan agregat pipih yang tinggi, dalam hal stabilitas dan durabilitas Marshall. Metode yang digunakan adalah Metode Marshall. Pada metode ini, total 27 benda uji dites. Hasil penelitian menunjukkan stabilitas beton aspal yang mengandung agregat yang dipecah adalah 38.8% lebih baik dibandingkan dengan beton aspal yang mengandung agregat yang tidak dipecah. Begitu juga, durabilitas beton aspal yang mengandung agregat yang dipecah 5.6% lebih baik daripada beton aspal yang mengandung agregat yang tidak dipecah.

Kata kunci: kerikil pipih, agregat yang dipecah, stabilitas Marshall

1 INTRODUCTION

The effect of various shape types of aggregate on asphalt concrete performance has been proven through laboratory testings and field data analysis. The laboratory testings involve triaxial (Herrin et al., 1954), Superpave (Tutumluer et al., 2005), Marshall (Jaya et al., 2014), dynamic creep (Jaya et al., 2014), while the field analysis involves rutting performance (Tutumluer et al., 2005).

The triaxial test was conducted to compare the performance of asphalt concrete containing crushed gravel with the same mixture containing uncrushed gravel. Asphalt concrete containing crushed gravel has higher performance compared to the same mixture containing uncrushed gravel. The higher crushed material content is, the stiffer asphalt concrete will be (Herrin et al., 1954; Goetz et al., 1959).

Permanent deformation was tested for asphalt concrete using Superpave gyratory compactor and image analyzer. In the test, the asphalt concretes were created from various shaped aggregates, both crushed and uncrushed aggerates, from 10 states in the USA. Based on the test, the angularity and texture of the aggregate improved the asphalt concrete stability (Tutumluer et al., 2005; Pan et al., 2005). The angular and coarse-textured aggregates support the asphalt concrete stability by doing particle geometrical interference. Particle geometrical interference means the coarse and fine aggregates interact with asphalts to prevent segregation (Tutumluer et al., 2005). The aggregate interactions include interlocking among the aggregates (Krebs and Walker, 1971).

The flat and elongated crushed granite has been compared with the cubical crushed granite in terms of the corresponding asphalt concrete performances. The asphalt concrete composed of cubical crushed granite has higher Marshall stability and better stiffness modulus. The stiffness modulus was tested using dynamic creep test (Jaya et al., 2014).

In addition, aggregate shapes also affect the field performance of asphalt concrete. Asphalt concrete composed of more angular and coarse-textured aggregates has better rutting resistance than the one composed of more rounded and smooth-textured aggregate. The fact was obtained with the help of the test track facility (Tutumluer et al., 2005).

However, no research has been found that compares the performance between the asphalt concrete composed of crushed gravel with high flat-particle content and the one composed of the same gravel uncrushed. The comparison is necessary since, in particular areas, the only available aggregate is gravel with high flat-particle content. Using the stone crushing machine, the angularity and texture of this aggregate can be improved, but the sphericity might not improve and conversely, could become flatter (Al-Rousan et al., 2005).

2 MATERIAL AND METHODS

The aggregate used in this study is gravel obtained from the Krueng Raya river, located in Aceh Province, Indonesia. The gravel mines are spread across at least 30 km of the Krueng Raya river. The natural gravels were collected from the mines. The crushed gravels were produced with the help of the stone crushing machine located near the river. The asphalt used in this study is 'Pertamina' asphalt of 60/70 penetration.

The asphalt concrete stability and durability were tested based on the Marshall test method. The test method refers to the Indonesian standard of RSNI M-01-2003. The test is divided into four main parts. Firstly, fulfilling the properties of the materials. Then, determining the optimum asphalt content of asphalt concrete. Next, testing the asphalt concrete stability. Finally, evaluating the durability of asphalt concrete.

2.1 Conforming Material Properties

The asphalt binder properties tested in this study are penetration, softening point, and density. The test values are shown in Table 1. The tests were performed based on the Indonesian standard, which is SNI 06-2456-1991 for penetration, SNI 06-2434-1991 for softening point, and SNI 06-2441-1991 for density. The requirement values for each test is 60 dmm to 79 dmm for penetration, 48 °C to 58 °C for softening point, and at least 1 for density.

Table 1. The Asphalt Binder Properties

Test Type	Requirement	Asphalt Binder Properties in This Study
Penetration, dmm	60 - 79	68.6
Softening point, °C	48 - 58	48.5
Density	≥ 1	1.03

The aggregate properties conformed are bulk density, water absorption, Los Angeles abrasion, attachment to asphalt, flakiness index, and elongation index. The standards used are as follows SNI 03-1969-1990 for both bulk density and water absorption, SNI 03-2417-1991 for Los Angeles abrasion, SNI 03-2439-1991 for attachment to asphalt, and ASTM D-4791 for both flakiness index and elongation index. The properties of aggregate used in this study are presented in the results part of this paper.

2.2 The Asphalt Concrete Samples

Table 2 and Table 3 shows the samples, corresponding asphalt content, along with the related test. The optimum asphalt content means the asphalt optimum obtained from the stability test across the uncrushed gravel-occupied asphalt concrete (sample A1 to A6). The optimum asphalt content was used as well for uncrushed-occupied asphalt concrete. The same asphalt content was used both for uncrushed and crushed aggregate due to the justification that the same gravel might generate the same corresponding asphalt concrete volumetric properties.

Table 2. The Samples Information (1)

Sample Code	Sample Total	Asphalt Content	Test
A1	3	3.5%	Stability
A2	3	4%	Stability
A3	3	4.5%	Stability
A4	3	5%	Stability
A5	3	5.5%	Stability
A6	3	Optimum	Stability
A7	3	Optimum	Durability
Total	21		

Note: aggregate type: uncrushed gravel

Table 3. The Samples Information (2)

Sample Code	Sample Total	Asphalt Content	Test
B1	3	Optimum	Stability
B2	3	Optimum	Durability
Total	6		

Note: aggregate type: crushed gravel

The asphalt concrete samples were prepared by firstly mixing the aggregate and asphalt at high temperature, then placing them into the mold with diameter of 10.2 cm and height of 6.35 cm. After that, the mixture was compacted 75 times on each area of the top and the bottom. Finally, the sample was released from the mold and placed at room temperature.

2.3 The Optimum Asphalt Content

According to RSNI M-01-2003, the optimum asphalt content for asphalt concrete is obtained from the optimum value of five series asphalt content. The asphalt content of every series refers to the Equation 1. The asphalt content series are Pb-1; Pb-0.5; Pb; Pb+0.5; Pb+1. Each series is represented by three samples.

$$Pb = 0.035\,(\%\,CA) + 0.045\,(\%\,FA) + 0.18\,(\%\,filler) + Constants \quad (1)$$

Where:

Pb = Percentage of binder (initial estimation) to the total asphalt concrete weight (%).

% CA = Percentage of coarse aggregate to the total aggregate weight (%).

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% FA	=	Percentage of fine aggregate to the total aggregate weight (%).
% filler	=	Percentage of filler to the total aggregate weight, (%).
Constants	=	0.5 %

The optimum value of five series asphalt content is obtained based on the fulfillment of the requirements of asphalt concrete's stability, -flow, -void of mineral aggregate (VMA), -void in mix (VIM), -void filled with asphalt (VFA), and -Marshall quotient. In this study, the optimum asphalt content is 5%.

2.4 Marshall Stability and Durability Test

The Marshall stability test is performed using the Marshall apparatus, which is equipped with proving ring and flow meter. Before being tested, the sample was submerged in water at 60 °C for 30 minutes. The outputs of the test are the values of Marshall stability, flow, and Marshall quotient.

The durability test is performed using the same Marshall apparatus. However, the duration of submerging sample is 24 hours in water at a temperature of 60 °C as well. The output of the durability test is the comparison between the stability of the sample soaked for 30 minutes and the one soaked in 24 hours.

3 RESULTS AND DISCUSSION

The uncrushed aggregate properties were shown in Table 4. The uncrushed aggregate has 2.75 of bulk density, 1.2% of water absorption, 17.4% of Los Angeles abrasion, and more than 95% of aggregate attachment to asphalt. All of the properties fulfill the standard. However, the aggregate has a higher amount of flat and elongated aggregate, which are 19% and 12% respectively.

Table 4. Properties of Uncrushed Aggregate

Property	Value	Requirement
Bulk density	2.75	≥ 2.5
Water absorption	1.2	≤ 3
Los Angeles abrasion	17.4%	≤ 40%
Attachment to asphalt	> 95%	≥ 95%
Flakiness index	19%	≤ 10%
Elongated index	12%	≤ 10%

The crushed aggregate properties were shown in Table 5. The uncrushed aggregate has 2.77 of bulk density, 1% of water absorption, 16.3% of Los Angeles abrasion, and more than 95% of aggregate attachment to asphalt. All of the properties fulfill the standard. However, the crushed aggregate also has a higher amount of flat and elongated aggregate, which are 38% and 12% respectively.

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Table 5. Properties of Crushed Aggregate

Property	Value	Requirement
Bulk density	2.77	≥ 2.5
Water absorption	1	≤ 3
Los Angeles abrasion	16.3%	≤ 40%
Attachment to asphalt	> 95%	≥ 95%
Flakiness index	38%	≤ 10%
Elongated index	12%	≤ 10%

3.1 Comparing the Abrasion Resistance

The crushed gravel is slightly more resistant to abrasion than the uncrushed gravel based on the Los Angeles abrasion test results. Both crushed and uncrushed gravel abrasion test values fulfill the standard. The uncrushed and crushed gravel is resistant enough to abrasion because, before being mined, the aggregate has been shaped by water flow in the river for years. The water strips the outer and weak parts of the gravel, so the remaining part of the gravel is the strong part. The crushed gravel has slightly higher abrasion resistance because the weak part of the aggregate has been split by the stone crushing machine. Based on the test results, the negative impact of the flat particle content on the abrasion resistance of the aggregate tested in this study is still within limits.

3.2 Comparing the Shapes

The uncrushed and crushed gravel has different angularity, texture, and flakiness. The uncrushed gravel is poor in angularity and texture, while the crushed gravel is excellent in angularity and texture. Both have flat particles, but the crushed gravel has flat particles twice than those of uncrushed gravel. This is because of the effect of the stone crushing machine that breaks the uncrushed particle and makes it become flatter. For the elongated particle content, both have the same value. So, the stone crushing machine used in this research does not change the elongated content of the gravel at before and after crushing. In conclusion, the positive impacts of the stone crushing machine are the angularity and texture, while the negative impact is the flat content.

3.3 Asphalt Content

The optimum asphalt content for asphalt concrete was decided by matching the characteristics of five types of asphalt concretes to the required value. The five types of asphalt concrete contain different asphalt content. The matched characteristics were stability, flow, void in mineral aggregate (VMA), and void in mix (VIM).

The comparison between the required stability and the asphalt concretes stability is shown in Figure 1. Based on Figure 1, the range of asphalt content satisfying the required stability is from 4.6% to 5.1%. The comparison between the required flow and the asphalt concretes flow is shown in Figure 2. Based on Figure 2, the range of asphalt content satisfying the required flow is from 4.5% to 5.5%. The comparison between the required VMA and the asphalt concretes VMA is shown in Figure 3. Based on Figure 3, the range of asphalt content satisfying the required VMA is from 5.1% to 5.5%. The comparison between the required VIM and the asphalt concretes VIM is shown in Figure 4. Based on Figure 4, the range of asphalt content satisfying the required VIM is from 4.4% to 5.5%. The final comparison result is shown in Figure 5. The decided optimum asphalt concrete is 5.1%.

3.4 Marshall Parameters: General

The Marshall test results are shown in Table 6. The uncrushed-gravel-occupied asphalt concrete has 5.6% of VIM, 16.1% of VMA, 65.3% VFA. All of the volumetric properties fulfill the standard, except VIM which slightly beyond the standard. In addition, the uncrushed-occupied asphalt concrete has 722.3 kg of stability, which is below the standard; 3 mm of flow, which is fit to the standard; and 240.8 of Marshall quotient, which is below the standard. The durability of the uncrushed-occupied asphalt concrete is 89.8%, which is fit to the standard.

The crushed-gravel-occupied asphalt concrete has 8.7% of VIM, 18.8% of VMA, 53.1% VFA. The VIM and VFA do not fulfill the standard, while the VMA fulfill the standard. In addition, the crushed-occupied asphalt concrete has 1003.2 kg of stability, 4 mm of flow, and 250.8 of Marshall quotient, all of those are fit to the standard. The durability of the crushed-occupied asphalt concrete is 94.2%, which is fit to the standard.

3.5 Marshall Parameters: Marshall stability

The stability of the asphalt concrete composed of crushed gravel is 38.8% higher than the one composed of uncrushed gravel. The high difference in stability between these asphalt concretes because of the angularity and texture of the aggregate. The negative impact of the high content of flat particle is still within limits due to the adequate stability of the crushed gravel occupied asphalt concrete, which contains the high flat particle.

3.6 Marshall Parameters: Volumetric properties

The volumetric properties of uncrushed-gravel-occupied asphalt concrete are better than those of crushed-gravel-occupied asphalt concrete. However, the too-high volumetric value of asphalt concrete composed of crushed gravel would not change the fact that the stability of this asphalt concrete is better than the one composed of uncrushed gravel. This is because the too-high volumetric properties only have a direct effect on durability. Moreover, in fact, the too-high volumetric value means the real stability could be higher than observed.

The out of limits volumetric properties of crushed gravel occupied asphalt concrete might be because of the low content of asphalt binder. The binder content which is based on the uncrushed gravel occupied asphalt concrete does not match the asphalt concrete containing the crushed gravel. Crushing gravel changes the asphalt binder need for the corresponding asphalt concrete.

3.7 Marshall Parameters: Durability

The durability of the asphalt concrete composed of crushed gravel is 5.6% better than the one composed of uncrushed gravel. The durability value of both asphalt concrete is high beyond the standard. The uncrushed gravel occupied asphalt concrete has the moderate durability value might be because of the lack of asphalt binder content. As discussed above, the asphalt content of the crushed-gravel occupied asphalt concrete can be optimal by adjusting the content of the binder.

4 CONCLUSIONS

The stability and durability of asphalt concrete composing crushed gravel with high flat-particle content is higher than the asphalt concrete composing the same gravel uncrushed. The stability and durability of asphalt concrete composed of the crushed gravel with a high content of flat particle fulfill the Indonesian standard. Crushing the gravel with high flat-particle content increases the flat particle content instead; however, the abrasion resistance of the crushed gravel is slightly higher than the uncrushed one.

Table 6. Asphalt Concrete Properties

Property	Type of Material		Requirement
	Uncrushed Gravel	Crushed Gravel	
VIM (%)	5.6	8.7	3.5 – 5.5
VMA (%)	16.1	18.8	≥ 15
VFA (%)	65.3	53.1	≥ 65
Stability (Kg)	722.3	1,003.2	≥ 800
Flow (mm)	3	4	≥ 3
Marshall quotient (Kg/mm)	240.8	250.8	≥ 250
Durability (%)	89.8	94.2	≥ 75

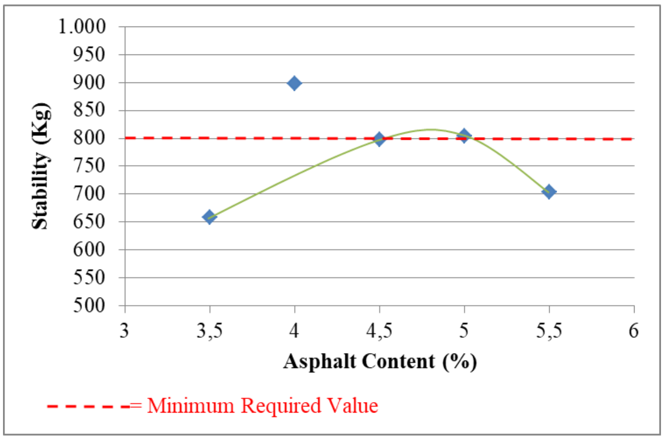

Figure 1. Allowed Asphalt Content Based on Stability

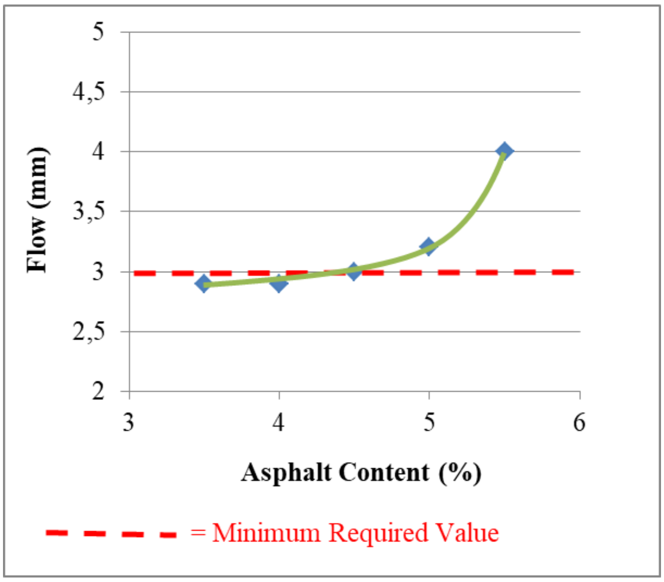

Figure 2. Allowed Asphalt Content Based on Flow

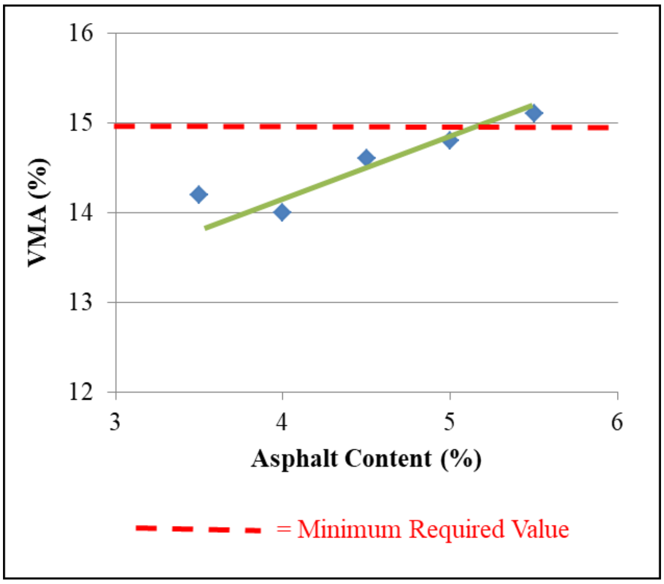

Figure 3. Allowed Asphalt Content Based on VMA

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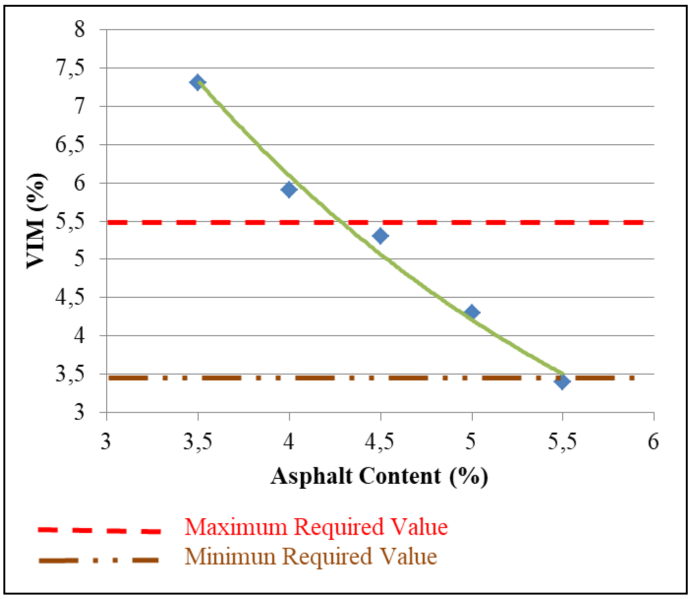

Figure 4. Allowed Asphalt Content Based on VIM

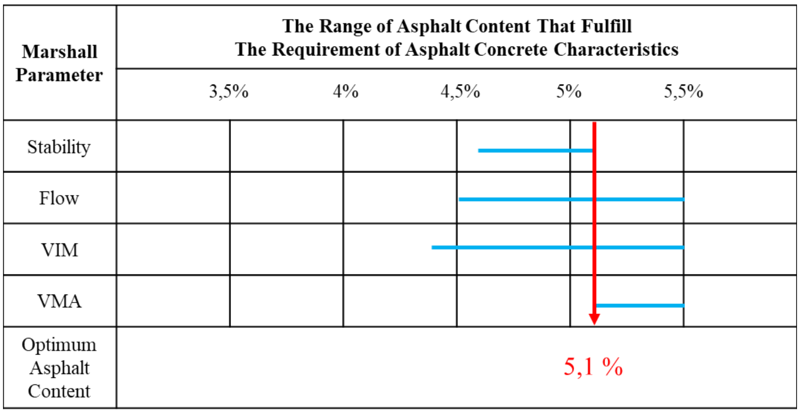

Figure 5. Comparison of Five Series of Asphalt Content on The Corresponding Asphalt Concrete

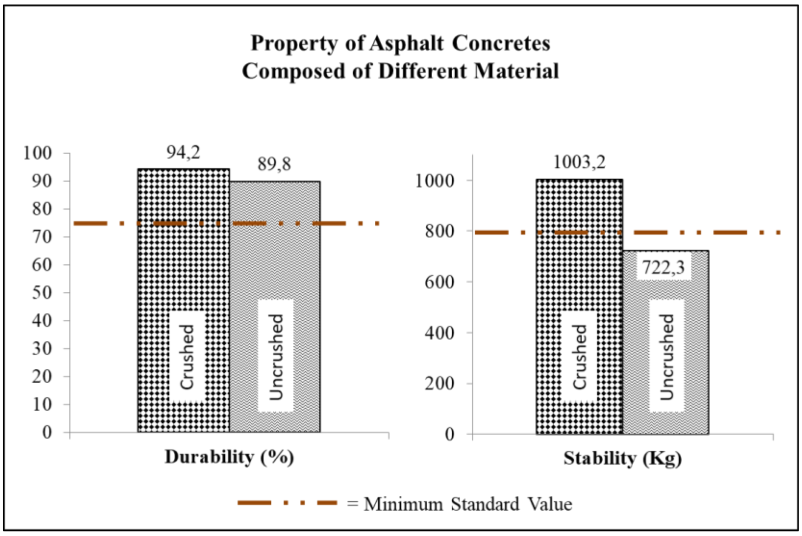

Figure 6. Property of Asphalt Concretes Composed of Different Material

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