

PAPER • OPEN ACCESS

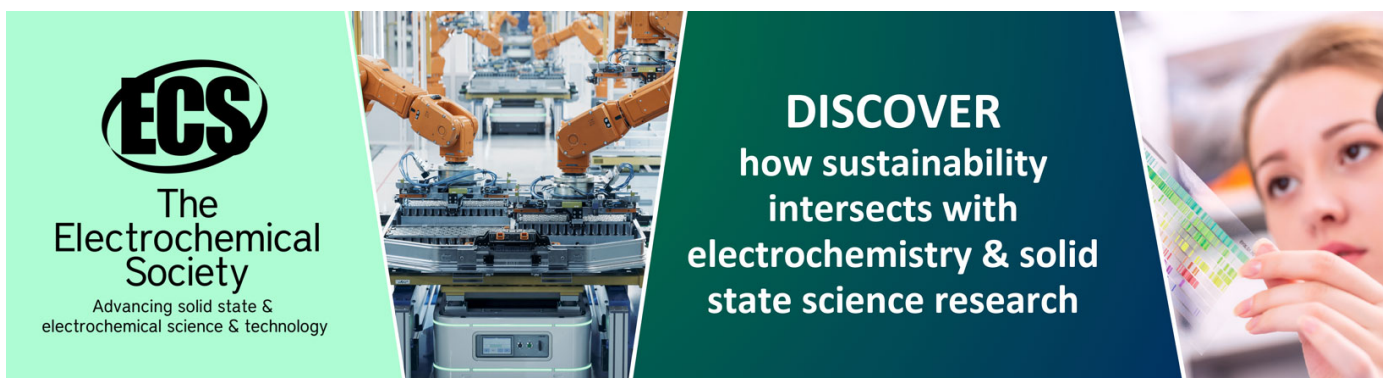
Gradation Design and Performance of OGFC-13 Steel Slag Permeable Asphalt Concrete

To cite this article: Shen Fan *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **688** 022017

View the [article online](#) for updates and enhancements.

You may also like

- [The Use of Steel Slag as Substitution of Coarse Aggregate on Indirect Tensile Strength and Marshall Properties of AC-WC](#)
A A Nugraha, M Fauziah and Subarkah
- [Preparation and mechanism of silicate-based sintering material from large amount of steel slag](#)
Minglong Ma, He Yang, Bing Bai et al.
- [Experimental evaluation of using stainless steel slag to produce mechanomutable asphalt mortars for their use in smart materials](#)
F Moreno-Navarro, G R Iglesias and M C Rubio-Gámez



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Gradation Design and Performance of OGFC-13 Steel Slag Permeable Asphalt Concrete

Fan Shen^{1*}, Ruonan Pang¹, Guosu Wei¹, Ji Lu², Sifa Fang²

¹School of Material Science and Engineering, Wuhan Institute of Technology, Wuhan, HuBei, 430205, China

²Wuhan Municipal Construction Group Co., Ltd., Wuhan, HuBei, 430023, China

*Corresponding author's e-mail: shenf@wit.edu.cn

Abstract. Steel slag permeable asphalt concrete was prepared with steel slag as aggregate and mineral powder as filler. The percentage passing rate of each grade of aggregate was calculated through the screening results of each grade of aggregate. The mixing ratio of five groups of raw materials was pre-designed according to the specifications of highway asphalt pavement, and the data with 2.36mm and 4.75mm as the key sieve holes were verified by mathematical regression method. Based on this, by testing the road performance of the standard Marshall specimens produced by the pre-designed five-component ratio, the optimal ratio of asphalt mixture with a voidage of 20.5% is obtained: w (13.2-9.5mm) : w (9.5-4.75mm) : w (4.75-2.36mm) : w (2.36-0mm) : w (ore powder) = 45:41:5:6:3. The Marshall stability of steel slag permeable asphalt mixture prepared according to this ratio is 6.07KN, 5.65KN by soaking Marshall, 93.08% by residual stability, 2698 times /mm by dynamic stability, and 45.3 by seepage coefficient. All technical indicators meet the requirements of asphalt pavement construction technical specification.

1. Introduction

Since the 20th century, China's road construction has been in a rapid development stage, most of which are asphalt pavement[1]. At present, 90% of asphalt pavement is designed and laid in accordance with the principle of dense grading, and the air voidance of the dense grading pavement is small, which makes the pavement prone to water accumulation and difficult to drain away[2]. Long period of road water not only seriously affects the driving safety of rainy road, but also greatly reduces the structural strength and performance of the inner layer of asphalt pavement, resulting in serious rutting[3].

The air space of permeable asphalt mixture can reach 18%-25%. In rainy days, most of the water will penetrate into the internal air space through the road surface and drain into the ground. In this process, the infiltration of dust will gradually reduce its permeability[4]. A large amount of rain water will stay in the road to several days or weeks, which will easily cause loose and peeling away road particles and form large pits, ultimately affecting the service life of permeable asphalt mixture[5]. Therefore, when designing permeable asphalt mixture, the selection of raw materials and mix ratio must be fully considered to ensure that permeable asphalt mixture has sufficient adhesion and water stability[6].

Steel slag is a kind of industrial waste. At present, the large-scale utilization of steel slag is very limited[7]. Using steel slag to build roads can not only reduce the exploitation of natural stone, but



also solve a series of problems caused by steel slag dumping. Steel slag has strong abrasion resistance and good angularity, and has good adhesion with asphalt[8]. In this paper, the OGFC-13 asphalt mixture was prepared for steel slag instead of natural aggregate.

2. Materials

The experimental coarse aggregate is steel slag, its particle size range is 13.2-0mm, the chemical composition and mechanical properties test results are shown in Table 1 and Table 2. The filler is the limestone ground fine ore powder provided by Jingzhou Lihua Trading Co., Ltd. Fiber is polyester fiber. Asphalt is heavy traffic paving petroleum asphalt.

Table 1. Chemical composition of steel slag

Chemical components	SiO ₂	Al ₂ O ₃	CaO	MgO	P ₂ O ₅	MnO	Fe ₂ O ₃	V ₂ O ₅	TiO ₂	K ₂ O	Na ₂ O	Cr ₂ O ₃
Content	9.47	3.11	43.54	2.70	1.24	4.98	29.58	0.39	1.84	0.08	0.08	0.41

It can be seen from Table 1 that the SiO₂ content of the steel slag is less than 10%, and the chemical combination with the asphalt help to improve the resistance of the permeable asphalt mixture road surface to water to damage.

Table 2. Steel slag mechanical properties test results

Performance Index	Adsorption rate /%	Crushing value /%	Los Angeles abrasion /%	Polishing value	Adhesion ability	Acicular content /%
Technical Requirements	≤3.0	≤28.0	≤28	>60	≥4 Grade	≤18.0
Test Results	1.89	14.5	12.2	71	4	14.8

It can be seen from Table 2 that the steel slag has a low water absorption rate of 1.89, which is an excellent aggregate of asphalt mixture, and has good adhesion, and ensures strong adhesion between the asphalt mixture.

3. Experimental scheme

3.1. Mixture synthesis grading design

According to *JTG E20-2011 "Testing Regulations for Asphalt and Asphalt Mixtures for Highway Engineering"*, the steel slag is screened, and according to the screening results of the aggregates, the preliminary design of the five groups satisfying the target void ratio of 20% is shown in Table 3. From Table 3, five different synthetic gradations were calculated by mathematical methods, so that the synthesis gradation rates of the particle sizes of 2.36 mm and 4.75 mm were different in each mixing ratio, and Table 4 is the synthetic gradation and the grading range.

Table 3. Content of each particle size

Material specification /mm	Steel slag (13.2-9.5mm)	Steel slag (9.5-4.75mm)	Steel slag (4.75-2.36mm)	Steel slag (2.36-0mm)	Mineral powder
Gradation 1	37	37	7	15.5	3.5
Gradation 2	39	39	6	12.5	3.5
Gradation 3	41	40	6	10	3
Gradation 4	43	41	6	7	3
Gradation 5	45	41	5	6	3

Table 4. Synthetic grading and grading range

	Percentage of perforated screens (%)										
Mesh	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Gradation 1	100	100	96.2	65.7	26.5	16.7	14.4	9.6	6.5	5.1	4.8
Gradation 2	100	100	96	63.9	23.4	14.9	12.9	8.9	6.2	4.9	4.6
Gradation 3	100	100	95.8	62.2	20.7	12.2	10.6	7.2	5.1	4.1	3.9
Gradation 4	100	100	95.6	61.4	17.8	10.4	9.1	6.4	4.6	3.9	3.7
Gradation 5	100	100	95.4	60.7	15.1	8.6	7.5	5.6	4.1	3.7	3.5
Median	100	100	95	70	21	16	12	9.5	7.5	5.5	4
Upper limit	100	100	100	80	30	22	18	15	12	8	6
Lower limit	100	100	90	60	12	10	6	4	3	3	2

3.2. Performance test

According to the requirements of *JTG E20-2011 "test regulations for asphalt and asphalt mixture of highway engineering"*, five groups of standard Marshall specimens with different grades were prepared with an empirical whetstone ratio of 4.6%, and the air void ratio, Marshall stability and immersed Marshall stability of the specimens were measured respectively. The rut specimen with the size of 300*300*50mm was made according to the requirements of the specification to test the water seepage performance and study its high temperature stability.

4. Results and Analysis

4.1. Regression curve and correlation of key sieve holes and void ratio

According to the research requirements, the general formula of the regression equation is,

$$Y=A+BX_1 \quad (1) \quad Y=A+BX_2 \quad (2)$$

X_1 —2.36mm mesh pass rate (%), Pass rate of X_2 —4.75mm mesh (%), Y — void ratio(%).

From the general form of the regression equation, it is a straight line equation, which can transform a complex scatter plot against a simple straight line fitting problem[9]. Five sets of data were taken within the experimentally measured void fraction range, and the relationship between the pass rate and the void ratio of the 2.36 mm and 4.75 mm mesh openings were observed and recorded. The test data results are shown in Table 5.

Table 5. void ratio and key sieve pass rate results

Porosity (%)	2.36mm mesh pass rate (%)	4.75mm mesh pass rate (%)
16.9	16.7	26.5
17.6	14.9	23.4
18.5	12.2	20.7
19.2	10.4	17.8
20.5	8.6	15.1

After analysis and calculation, the fitting curve is shown in the regression curve of Figure1. The thick line of the figure is the original data, and the thin line is the fitting data.

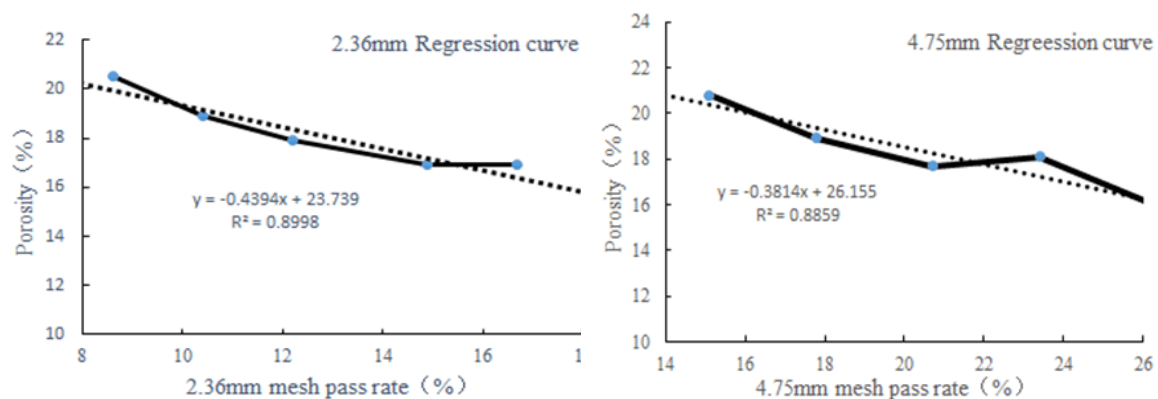


Figure 1. Regression curve

From Figure 1, the equations for the two key mesh regression curves are $y = -0.4394x + 23.739$, $R^2 = 0.8998$ and $y = -0.3814x + 26.155$, $R^2 = 0.8859$. Since the R^2 value of 2.36mm is larger than the R^2 value of 4.75mm, the pass rate of 2.36mm mesh has a more influence on the void ratio, and the regression curve is basically consistent with the test curve, that is, the test data is verified. It is proved that the method of finding the controllable void ratio by analyzing the regression curve is feasible, and it is also proved that the designed mixture ratio can reach the target porosity.

4.2. OGFC-13 steel slag permeable asphalt mixture performance test

4.2.1. Marshall stability and water stability. The Marshall stability and the water immersion Marshall stability test were carried out on the mixture test pieces prepared by the five groups. The results are shown in Table 6.

Table 6. Marshall Performance Test Results

	Porosity %	Marshall stability (KN)	Soaking Marshall stability (KN)	Residual stability (%)
Gradation 1	16.9	7.83	7.41	94.64
Gradation 2	17.6	7.52	6.57	87.36
Gradation 3	18.5	7.27	6.15	84.59
Gradation 4	19.2	6.55	5.89	89.92
Gradation 5	20.5	6.07	5.65	93.08
Technical index	18-25	≥ 3.5	—	≥ 85

It is known from Table 6 that the Marshall stability and the water-immersed Marshall stability of the test pieces at all levels show a decreasing trend with the increase of the void ratio, because the smaller the void ratio, the more the asphalt content, the aggregate in the asphalt mixture and The stronger the asphalt adhesion, the better the water damage resistance, and the stability of the water-immersed Marshall showed a downward trend. Considering that the asphalt mixture not only has better drainage performance, but also have the water stability performance according to the specification, the mix ratio of the target 5 voids ratio of 20% is more suitable. The Marshall stability is 6.07KN, soaking Marshall. The stability was 5.65 KN and the residual stability was 93.08%.

4.2.2. Water seepage test. The water permeability coefficient is a macroscopic response to the void ratio of the asphalt mixture, and is an important indicator of the drainage performance of the

permeable asphalt mixture[10]. According to the JTG E20-2011 "Experimental Rules for Asphalt and Asphalt Mixtures for Highway Engineering", the five groups of grading tests were carried out by using the pavement tester. The results are shown in Table 7. It is known from Table 7 that the water permeability coefficient of the gradation ratio of the target void ratio of 20% is the largest, which is 45.3 ml/min.

Table 7. Water seepage test results

	Gradation 1	Gradation 2	Gradation 3	Gradation 4	Gradation 5
Water permeability coefficient(ml/min)	36.6	36.8	38.7	41.2	45.3

4.2.3 High temperature stability. The high-temperature rutting performance tested was carried out on the five-group rut test specimens. The results are shown in Table 8.

Table 8. rutting test results

	Porosity %	Rutting (frequency /mm)
Gradation 1	16.9	3234
Gradation 2	17.6	3059
Gradation 3	18.5	2971
Gradation 4	19.2	2814
Gradation 5	20.5	2698
Technical index	18-25	> 1500

It is known from Table 8 that as the void ratio increases, the dynamic stability decreases sharply, and the change in the void ratio greatly affects the rutting performance. The reason for the analysis is that the size of the void ratio determines the degree of inlaying of the internal structure of the asphalt mixture. The larger the void ratio, the less dense the aggregate are, and the less free asphalt in the asphalt mixture. When the traffic load acts on the surface of the mixture, the larger the void ratio is, the more compact the structure is, the easier it is to compress downward. The less the free asphalt content, the weaker the recovery deformation ability, and the easier it are to produce rutting.

5. Conclusion

(1) This paper takes OGFC-13 steel slags permeable asphalt mixture as the research object. In the grading range, five sets of target vacancies at a target void ratio of 20% were designed. The mathematical regression method was used to select the meshing holes of 2.36mm and 4.75mm, and the screening results were data sorted and fitted. The conclusion was the fit between the void ratio and the two key screens of 2.36 mm and 4.75 mm is roughly consistent with the curve obtained from the test. After analysis, the pass rate of the key sieves meets the requirements, which indicates that the tested test data is desirable. It will play an important guiding role in the future research on the initial void ratio of asphalt mixture to achieve the target void ratio.

(2) By comparing the other four groups of experiments, the gradation 5 closest to the target void ratio was determined, and the void ratio reached 20.5% and its oil-stone ratio was 4.6%. The prepared steel slag permeable asphalt mixture Marshall stability is 6.07KN, the water immersion Marshall stability is 5.65KN, the residual stability is 93.08%, the dynamic stability is 2698 times/mm, and the water permeability coefficient is 45.3. All performance indicators are in line with the national technical standards such as "Technical Specifications for Highway Asphalt Pavement Construction" (JTG F40-2004), which can be used for actual construction.

Acknowledgments

Thanks to NO: CX2018068, Supported by Graduate Innovative Fund of Wuhan Institute of Technology. as well as the Wuhan Municipal Construction Group Co., Ltd. Science and Technology Project, snow-melting drainage and anti-slip asphalt pavement Material design and paving technology (wszky201708) gave support for this study.

References

- [1] Zhu, M,L., Wang, M., Qiu, X,G. (2018) Analysis of Influence of Air Void on Performance of Asphalt Mixture., Journal of Transportation Science and Engineering, 21: 25-31.
- [2] Li, W,S., (2008) Discussion on Correlation between Water Damage and Voidage of Asphalt Pavement., Journal of Highway and Transportation Research and Development, 69-70.
- [3] Dong, X., Wang, J,G., (2010) Research on pavement materials and engineering application of water-permeable pavement. , Subgrade Engineering, 26: 39-42.
- [4] Liu,Y., (2014) Research on road characteristics of large gap permeable asphalt pavement. Chang'an University.
- [5] Xu,B. (2011)Theory and Practice of Drainage Asphalt Pavement. People's Communications Press.
- [6] Xing, M, L., (2007) Study on composition design and performance of water-permeable asphalt mixture. Chang'an University.
- [7] Zhai, L,P., Wu, H,Y., (2019) Innovation and Practice of Recycling Utilization of Ninggang Steel Slag. , Metallurgical Energy, 38: 46-48.
- [8] Bai, M., Shang, J, L., et al. (2018) Experimental study on the preparation of concrete by replacing steel slag with coarse aggregate. , Concrete, 62-70.
- [9] Chen, Q, S., Tang, J, B., Huang, S, L., et al. (2008)Application of Mathematical Regression Method in Gradation Design of Large Pore Asphalt Mixture., Journal of Transportation Science, 54-56.
- [10] Xu ,W., Ni, F, J., Liu, Q, Q., et al.(2004) Test of Permeability Coefficient of Drainage Asphalt Mixture. , China Journal of Highway and Transport, 17:1-5.