Experimental Research on the Effect of Compaction on the Properties of Hot Mix Asphalt Concrete

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Abstract **- The article presents some results of experimental research on the effect of compaction on some technical characteristics of hot mix asphalt BTNC12.5 with bitumen class 60/70 in Vietnam's conditions. Investigation of the characteristics of asphalt concrete samples BTNC12.5 prepared in the laboratory with different compaction levels, has been completed. Experimental data obtained showed that the coefficient of compaction has significant effect on the Marshall stability, Marshall plasticity index, splitting tensile strength and rutting resistance tested in the laboratory with Hamburg Wheel Tracking Device. This result indicates the preliminary decline in quality of hot mix asphalt concrete when the compaction coefficient is not guaranteed.**

Keywords: Hot Mix Asphalt, Quality Of Compaction, Marshall Stability, Marshall Plasticity, Rutting Resistance.

1. INTRODUCTION

Exploitation property, load-bearing strength and durability of asphalt concrete (AC) depends on a variety of factors, from selection of input materials to the design of AC mixed component and construction quality as well, including compaction [10, 11]. In addition to ensuring the quality of materials as well as the design of AC mixed components, during the compaction, compaction density is a fundamental parameter for ensuring the technical specifications of AC in pavement structure to be equivalent to the design indexes [7, 8]. As stated in TCVN 8819-2011 Standards, the AC construction compaction density (i.e. the ratio between the volume of AC sample bored from the pavement and the volume of AC sample prepared in the laboratory under Marshall method in temperature corresponding to the type of bitumen used) is specified to be not less than 0.98 [2]. In fact, during the construction process, AC compaction density in some positions does not meet this requirement due to many different factors. According to the Guidelines on the application of technical standards issued in conjunction with Decision No.858/QD-BGTVT in 2014, the average value of boring samples is allowed to be measured as the parameter for measuring the compaction density of the inspected road section, i.e. the compaction density of the inspected section is considered as satisfactory when some (less than 40%) of the samples have a compaction density of less than 0.98 [1]. Therefore, the specific data shall be required for studying and evaluating the characteristics of AC with different compaction degrees (greater than or less than 0.98).

2. EFFECTS OF COMPACTION ON THE PROPERTIES OF ASPHALT CONCRETE

AC compaction is a complex process that requires a high level of focus, a reasonable arrangement of compacting equipment, experience in coordinating the construction equipment and ensuring the temperature of AC mixture in the compacting process. The combination of compacting equipment, compacting conveyor, sequence of execution, vibrating compaction frequency and amplitude determine the efficiency of the compaction, so that the construction units are required to be precise at the trial construction. In case one or more of the above factors are not guaranteed, resulting in unguaranteed compaction coefficient of AC after finishing the compaction, causing high residual void, decreasing the physio-mechanical properties of asphalt concrete. Some studies have shown that a 1% increase in compaction coefficient can increase the compressive strength of AC to about 10-12% [9].

The AC does not guarantee the compaction density as required, resulting in higher residual void than the design residual void, so the density of links in the micro-structure of the AC will decrease, accordingly. The large AC residual void allows oxygen in the air to have more space for contacting with the bitumen membrane, leading to an increase in the aging speed of the AC. Besides, in the humid climate condition, in the rainy season, large residual void is also a factor in accelerating the peeling process, destroying the AC structure under the effect of water. Unguaranteed compaction density of AC leads to a reduction in the compressive strength at 20°C and 50°C, increase of water saturation, reduction in asphalt cutting resistance (angle of internal friction φ and cohesion c) and acceleration of the accumulating process of non-recovering deformation on the AC pavement in the form of rutting damage [4, 5, 11].

3. EXPERIMENTAL RESEARCH PLAN

The research subject of the article is hot mix asphalt BTNC12.5 with aggregate component complying with the requirements of the Guidelines issued in conjunction with Decision No. 858/QD-BGTVT in 2014. The aggregates for AC using coarse and fine aggregates from Tran Voi rock quarry (Quoc Oai - Hanoi), Kien Khe mineral filler (Ha Nam), bitumen with grade according to penetration index of 60/70 is supplied by ADCo.

Hot mix asphalt BTNC12.5 is designed with mixed component according to Marshall method [3], the aggregate component is shown in Figure 3.1. The aggregate content D_{max} 20mm, D_{max} 10mm, D_{max} 5mm is 23, 40 and 32% respectively. Mineral filler powder content used is 5%, the optimal bitumen content under the design is 4.6%. AC is designed with the above content and has technical specifications meeting the requirements of TCVN 8819:2011 Standards and Decision No. 858/QD-BGTVT with the average residual void of samples reaching 4.59%, the largest density of AC is in a loose state G_{mm} = 2.688.

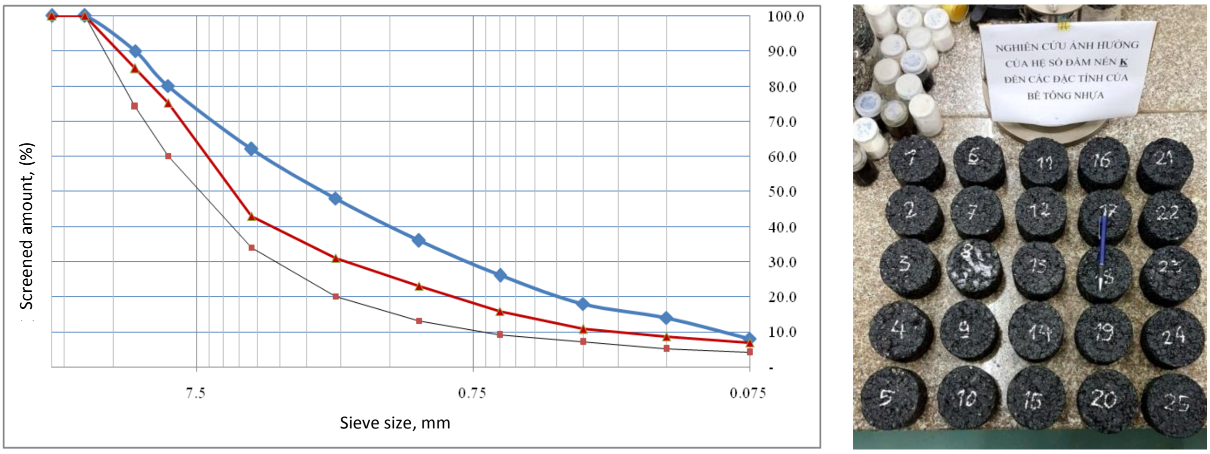

Figure 3.1: Aggregate component of hot mix asphalt BTNC12.5 and samples prepared by rotary rammer

Based on the AC design data, rotary rammer is used to prepare AC samples with the same standard height of 63.5 mm and different compaction degrees (residual void) by varying the number of compacting times (Figure 3.1). AC samples prepared by rotary rammer were tested to determine the volume, residual void, Marshall stability, plasticity index, residual stability (in accordance with TCVN 8860: 2011 Standards), splitting tensile strength at 15°C (in accordance with TCVN 8862:2011 Standards). The AC samples are prepared to test the rutting resistance in water at a temperature of 50°C on Hamburg Wheel Tracking Device (Figure 3.2). The testing procedure complies with the Technical Guideline issued in conjunction with Decision No. 1617/QD-BGTVT in 2014. In the rutting test, AC samples with low compaction density are soon destroyed before 15,000 turns of wheel, thus the rutting depth of 10,000 turns is selected as a comparison benchmark. The number of samples of each test is shown in Table 3.1.

Table 3.1: Number of experimental research samples

	Experiment			
	Marshall stability	Plasticity	Splitting tensile R	Rutting
Number of samples	4x6=24	4x6=24	4x6=24	2x4=8

Figure 3.2: Rutting and splitting tensile strength test

The Marshall experiment was conducted with a device that allowed collecting and re-drawing the force-strain diagram to determine stability and plasticity indexes in accordance with ASTM 6927 (Figure 3.3).

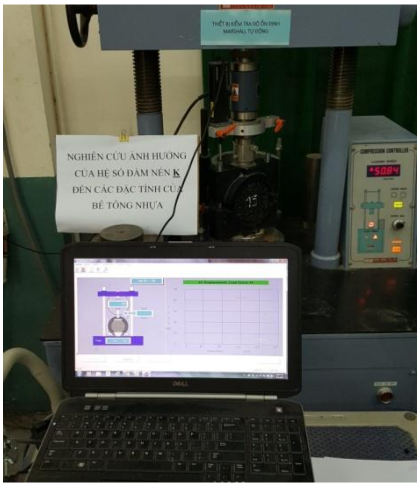

Figure 3.3: Marshall test and stability determination in accordance with ASTM 6927

4. RESULTS OF THE TESTING RESEARCH AND EVALUATION

The test was conducted in laboratory LAS-XD72 of the University of Transport Technology, testing procedures were strictly complied with the current standards. AC samples prepared by rotary rammer after the test were divided into 4 groups with compaction coefficient (ratio of volume to design) is K101.3, K98.8, K96.6 and K93.2, respectively, with residual void of 3.3%, 5.6%, 7.8% and 11.1%, respectively. Data collected were processed statistically and presented in Table 4.1 and Table 4.2.

Table 4.1: Test results of determining Marshall stability and plasticity index

Marshall stability, kN					Marshall plasticity, mm				
Compaction coefficient	1.013	0.989	0.966	0.932	Compaction coefficient	1.01	0.99	0.97	0.93
Residual void, %	3.30	5.60	7.88	11.03	Residual void, %	3.30	5.60	7.88	11.03
Sample 1	13.02	10.63	8.48	5.66	Sample 1	2.7	2.88	3.25	4.41
Sample 2	14.20	10.82	8.31	4.86	Sample 2	2.64	2.76	3.185	4.06
Sample 3	12.71	9.93	8.1	4.72	Sample 3	2.58	2.7	3.315	4.13
Sample 4	14.42	10.81	8.8	5.78	Sample 4	2.76	2.94	3.12	4.34
Sample 5	13.24	10.94	8.02	4.94	Sample 5	2.58	2.82	3.38	4.06
Sample 6	13.81	11.11	8.65	5.65	Sample 6	2.76	2.88	3.055	4.48
Average, μ	13.57	10.71	8.39	5.27	Average, μ	2.67	2.83	3.22	4.25
Standard deviation, σ	0.682	0.412	0.307	0.477	Standard deviation, σ	0.083	0.088	0.122	0.186
C_V, %	5.0%	3.9%	3.7%	9.0%	C_V, %	3.1%	3.1%	3.8%	4.4%

The test results show that when the AC compaction density varies from 101.3 to 93.2, Marshall stability at 60°C varies from 13.57 to 5.27 kN, and Marshall plasticity index varies from 2.67 to 4.25 mm (Figure 4.1). Under TCVN 8819: 2011 Standards, Marshall stability is controlled at equal or more than 8.0 kN, plasticity is in the range of 1.5 to 4.0mm, so the AC samples with compaction density of K93.2 do not meet the minimum requirement of the Standards. Marshall stability reduction of AC samples with compaction coefficients of K96.6 and K93.2 compared to the samples with K98.9 was 78.4% and 49.2%, respectively; the plasticity increased by 13.7% and 50%, respectively. At K93.2, the Marshall index was approximately two times lower than the K98, resulting in a significant decline in road surface quality. At K96.6 (which is also relatively common in non-professional construction), Marshall indexes are at the lower threshold of the Standard requirements, significantly decreasing the quality as well as lifespan of the road surface. Compacting at K101.3 increases Marshall stability to 26.7% and reduces the plasticity by 6% (Figure 4.1), according to Marshall design principle, which demonstrates that the destruction resistance strength of the AC is improved. However, other indicators need to be balanced, including rutting resistance.

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Table 4.2: Test results of splitting tensile strength at 15 ºC and rutting

Splitting tensile strength at 15 ºC, MPa					Rutting depth after 10,000 turns, mm				
Compaction coefficient	1.01	0.99	0.97	0.93	Compaction coefficient	1.01	0.99	0.97	0.93
Residual void, %	3.30	5.60	7.88	11.03	Residual void, %	3.30	5.60	7.88	11.03
Sample 1	2.11	2.54	1.61	1.25	Sample 1	2.20	1.95	3.75	9.80
Sample 2	2.52	2.24	1.73	1.44	Sample 2	2.40	2.10	4.10	10.50
Sample 3	2.55	2.65	1.84	1.22	Sample 3				
Sample 4	2.31	2.21	1.65	1.39	Sample 4				
Sample 5	2.51	2.24	1.77	1.35	Sample 5				
Sample 6	2.43	2.58	1.78	1.24	Sample 6				
Average, µ	2.405	2.410	1.730	1.315	Average, µ	2.30	2.03	3.93	10.15
Standard deviation, σ	0.168	0.201	0.086	0.091	Standard deviation, σ	0.141	0.106	0.247	0.495
C_V, %	7.0%	8.3%	5.0%	6.9%	C_V, %	6%	5.2%	6.3%	4.9%

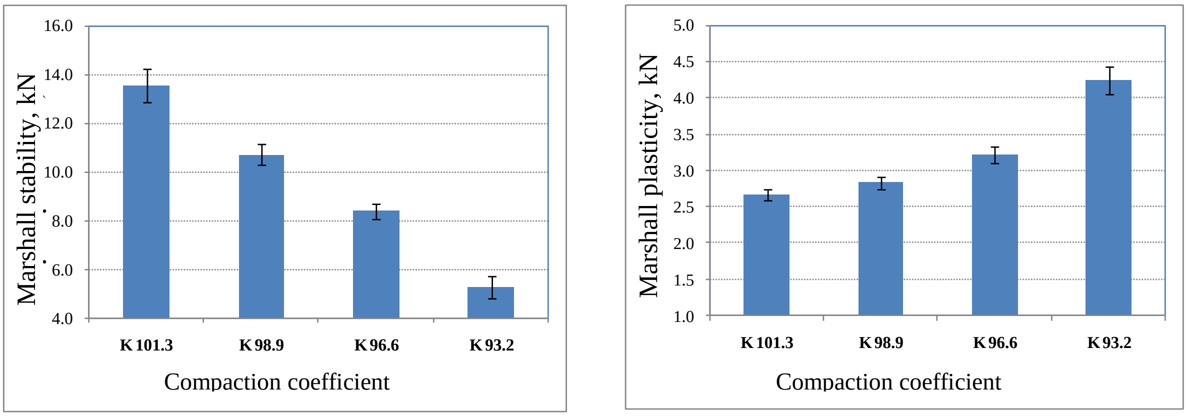

Figure 4.1: Effects of compaction coefficient on Marshall indexes of asphalt concrete

Similar to the Marshall Stability rules, the splitting tensile strength at 15°C significantly falls as the AC's compaction coefficient decreases. Compared with AC samples with K98.9 compaction coefficient, the splitting tensile strength at 15 °C of the AC samples with K96.6 and K93.2 compaction coefficient declines 28.2% and 45.4%, respectively (**Table 4.2**). This decline demonstrates that the tensile strength at low temperatures of the AC surface considerably decreases compared with the calculation, especially at the positions of K93.2 which decreases at approximately 2 times, which is the cause of early damage on the road surface in the form of cracks.

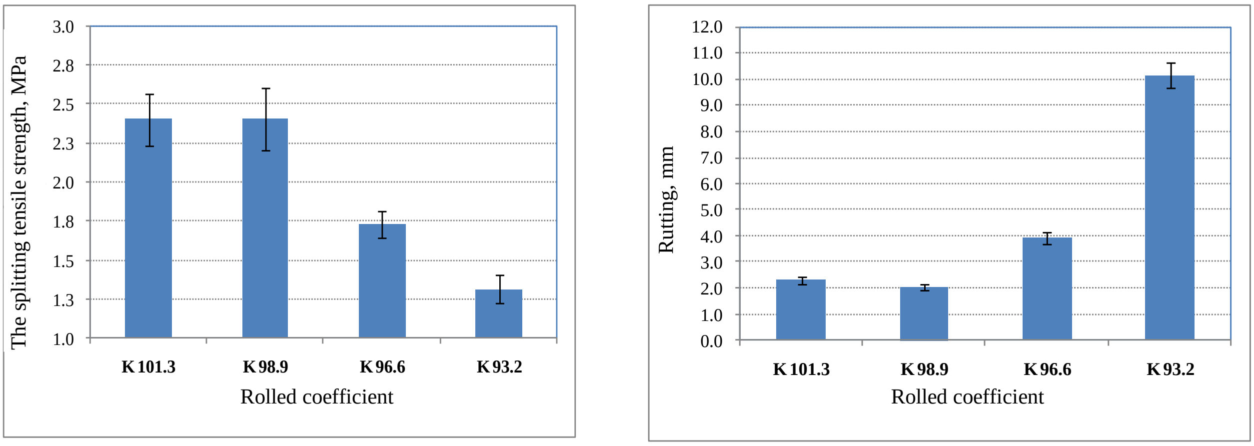

Figure 4.2: Effect of compaction coefficient to splitting R and rutting depth

Rutting test in water at 50^{o}C on the Hamburg Wheel Tracking device shows that the rutting depth of AC samples with compaction coefficient K101.3 is higher than the AC with compaction coefficient K98.9, the average rutting depth value after 10,000 records is 2.3 mm and 2.03 mm, respectively (**Table 4.2** and **Figure 4.2**). This is interpreted from the viewpoint of the author when low residual void leads to structural change of the AC due to thermal expansion of bitumen that is insufficient to fill with residual void of 3.3%, resulting in a displacement of a part of the adhesive component (free bitumen) causes instability during the bearing process of the AC. However, due to few number of sample (2 samples), it is not reliable enough to evaluate the rutting resistance decrease due to low residual void.

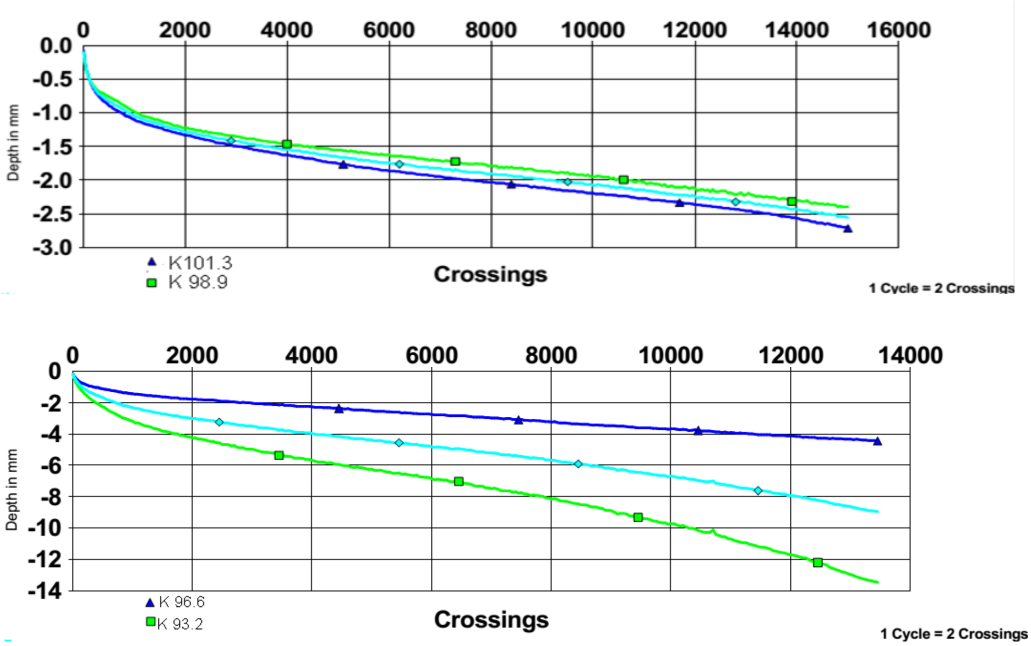

Figure 4.3: Excess distortion accumulation in rutting test of AC samples

For AC samples with compaction coefficient K96.6 and K93.2, the AC's rutting resistance decreases rapidly (Figure 4.3). Especially AC samples with rolled tightness K93.2, these samples are destroyed before 15,000 turns of wheels. For AC samples with compaction coefficient K96.6, the rutting depth after 10,000 increases approximately twice compared with K98.9; For AC samples with compaction coefficient K93.2, rutting depth after 10,000 increases approximately 5 times compared with K98.9 (Table 4.2). According to the authors' point of view, the low compaction coefficient leads to increase in residual void of AC samples, resulting in post compaction during the repetitive loading process is the cause of increasing the rutting depth. In addition, due to low compaction coefficient, resulting in the incompleteness in AC structure, the AC load-bearing aggregate structure under the design is not guaranteed, leading to the easier transition of the aggregate system in the load-bearing process, is the main cause of increasing the rutting depth (Figure 4.4).

Figure 4.4: Image of AC sample after rutting test

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The AC's moisture resistance with different compaction coefficient is evaluated through the remaining Marshall stability after 24 hours of immersion in water at 60°C. The test results show that the moisture resistance of AC samples with compaction coefficient K96.6 and K93.2 decreases by 7% and 9%, respectively. The moisture resistance of AC sample with compaction coefficient K101.3 is 7% higher than AC sample with compaction coefficient K98.9 (Figure 4.5).

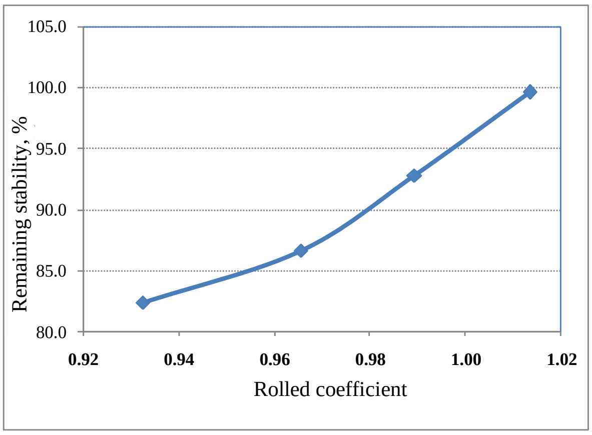

Figure 4.5: Effect of compaction coefficient to AC's moisture resistance

5. CONCLUSIONS AND RECOMMENDATIONS

Through the laboratory research results with a kind of asphalt concrete commonly used as the upper surface of the pavement (BTNC12.5) which shows that the compaction coefficient is an important construction parameter to ensure the quality of AC in road pavement, in accordance with the parameters when conducting the design of the mixture. When the compaction coefficient fails to meet requirements (less than 0.98) resulting in a various decrease in AC specifications as well as changes in the load-bearing nature of the material in the stress-strain state (Figure 5.1).

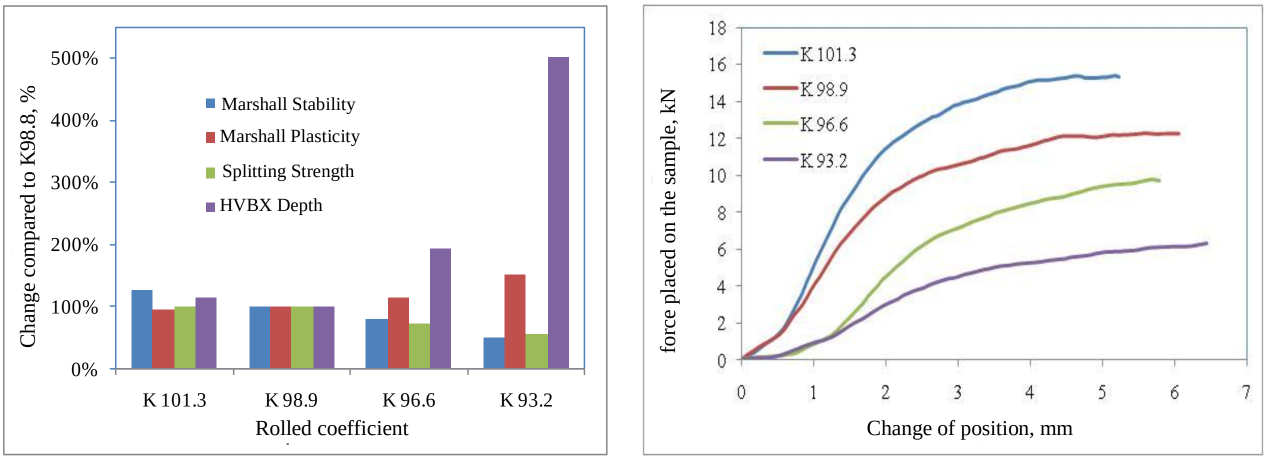

Figure 5.1: Effect of compaction coefficient to AC's technical and mechanical characteristics

For AC samples with relative compaction coefficient close to K98, significant technical specifications decreased approximately 2 times (Marshall Stability, Marshall Plasticity, rutting Resistance). In line with the Guideline on applying the standards issued in conjunction with Decision No. 858/QD-BGTVT in 2014, it is necessary to consider and evaluate the positions that do not gain the compaction coefficient although the road section still meets criteria of average compaction coefficient of more than 0.98 (or less than 40% of the boring position with K98).

For AC samples with low compaction coefficient (K93.2), besides the residual void parameters that do not meet technical requirements, AC's technical criteria severely decreased, failing to meet technical requirements, it could cause early damage of the pavement in various forms (wheel's rutting, tracking, peeling, cracking, potholes, etc.). Consideration should be given to the possibility of scratching, peeling the newly-constructed pavement right after inspection in order to avoid early damage to the sections with low compaction coefficient.

For more complete evaluation data, extensive researches should be done on asphalt concrete with bitumen classes (40/50, 60/70 and PMB) and evaluation should be conducted with actual construction samples on the road pavement compared with the condition of the pavement to be put into operation so as to possibly set up the procedures for accepting the value reduction (corresponding to the quality) and the compulsory requirements for removing the damage and conduct a new construction.

REFERENCES:

[1] Ministry of Transport (2014). Decision No. 858/QD-BGTVT on promulgating the Guidelines on applying the system of current technical standards in order to enhance the quality management of design and construction of hot asphalt concrete road pavement for large-scale automobile roads.
[2] Vietnamese Standard, TCVN 8819:2011. Hot asphalt road pavement – requirements for construction and acceptance.
[3] Vietnamese Standard TCVN 8820:2011. Hot asphalt mix – Design by Marshall method.
[4] Kassem, E., Scullion, T., Masad, E. & Chowdhury, A. 2012. Comprehensive evaluation of compaction of asphalt pavements and a practical approach for density predictions. Transportation Research Journal: Journal of Transportation, Research Board 2268: 98-107.
[5] Decker, D.S., (2006). State of the practice for cold weather compaction of hot mix asphalt pavements. Optimizing hot-mix asphalt construction temperature. Factors Affecting Compaction of Asphalt Pavements. Transportation Research Circular E-C105. Transportation Research Board of the National Academies. ISSN 0097-8515.
[6] Asphalt Institute (2003). "Superpave Performance Graded Asphalt Binder Specifications and Testing". Asphalt Institute 2003.53 p.
[7] Austroads Project No. TT1354 (2010)."Laboratory Study on Relationship between Binder Properties and Asphalt Rutting". Sydney 2010. 53 p.
[8] Petersen, J.C. et al. "Binder Characterization and Evaluation", Volume 1. SHRP-A- 367, Strategic Highways Research Program, National Research Council, Washington, D.C., 1994.
[9] Kotlyarskiy, E.V. Durability of road asphalt-concrete coatings and factors contributing to the destruction of the structure of asphalt concrete during operation. / E.V. Kotlyarsky O.A. Voeiko M .: Tehpoligratsentr, 2007.
[10] Zolotarev VA Durability of road asphalt concrete / VA Zolotarev. Kharkov: Higher Education. Shk., 1977. 155 p.
[11] Rudensky, AV Experience in the construction of road asphalt-concrete coatings in different climatic conditions / AV Rudensky. -M. : Transport, 1983. - 64 p.