International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Environmental and Earth Sciences Research Journal
Vol. 9, No. 2, June, 2022, pp. 44-48
Journal homepage: http://iieta.org/journals/eesrj

# Road Performance of an Overlay Material Improved by Rubber Powder Dry-Processing Method in Cold Regions

Wenyue Liu[1], Baoxiang Liu[2], Zhou Qiu[3], Chuanfeng Zheng[4*], Haisong Luo[1], Zhi Lin[1]

[1] College of Construction Engineering, Jilin University, Changchun 130061, China
[2] Haiwei Engineering Construction Co. Ltd of FHEC of CCCC, Beijing 101119, China
[3] CCCC Third Highway Engineering Co., Ltd., Beijing 100011, China
[4] School of Transportation, Jilin University, Changchun 130022, China

Corresponding Author Email: cfzheng@jlu.edu.cn

https://doi.org/10.18280/eesrj.090204

**Received:** 18 April 2022
**Accepted:** 3 June 2022

***Keywords:***
*road engineering, dry process, Rubber Powder (RP), thin-layer overlay material, gradation, low temperature performance*

**ABSTRACT**

This paper studied a thin-layer overlay material used in cold regions, aiming to solve the contradiction between the low-temperature crack resistance and skid resistance of asphalt mixture. At first, this paper adopted a dry-processing method to solve the possible segregation problem of Rubber Powder (RP)-modified asphalt in real engineering practice, the proportion of minerals in the proposed material was adjusted within the grading range of Stone Mastic Asphalt (SMA)-10 for the purpose of attaining asphalt mixture that has satisfactory strength and usability. Then, the proposed material was subject to low-temperature splitting test and Cantabro raveling test to verify its low-temperature cracking resistance and disintegration resistance, and two parameters British Pendulum Number (BPN) and Mean Profile Depth (MPD) were applied to evaluate the skid resistance of the proposed thin-layer overlay material, and the test results showed that, the proposed RP-modified asphalt processed by the dry method had very good low-temperature performance, the medium-coarse SMA-10 gradation can well balance the strength and skid resistance of the material, and enhance the applicability of thin-layer overlay material in cold regions.

## 1. INTRODUCTION

Pavement repairing and maintenance are important works in road engineering. As the service time of the roads increases, problems such as insufficient friction, surface cracking, performance degradation, and appearance defects might occur to road surface, so targeted solutions are required for solving these issues [1]. Thin-layer overlays have received extensive attention ever since their inception. Compared with repairing and sealing maintenance, thin-layer overlays can deal with a wider variety of diseases and damages, and they can modify surface defects and improve the overall smoothness and skid resistance of the road surface [2, 3]. Generally, a high cohesion is required for asphalt mixture used in thin-layer overlays, so modified asphalt is usually used instead of common asphalt, and researchers have done a lot of experiments and used various modifiers to improve the modification effect, and it's found that compared with other types of modified asphalt, the RP-modified asphalt has better crack resistance in low temperature environment [4, 5], however, for the ordinary RP-modified asphalt processed by the wet method, due to the discontinuous preparation and utilization processes, segregation might occur during storage and transportation, and some studies have proved that, after stored for more than 12 hours, RP-modified asphalt would exhibit serious segregation problem [6]. If this material is used in pavement, problems such as incompact surface might show up, in severer cases, it might cause surface cracking or wheel ruts; while the dry process has the feature of "use right after mixed", which can effectively solve the segregation problem and ensure the uniformity of the material, thereby reducing the possible damages to the road surface [7, 8]. For thin-layer overlays used in cold regions, another problem to be solved is the improvement of skid resistance performance, and the contradiction between the strength and skid resistance of the thin-layer overlay material can be solved by adjusting the content of coarse and fine aggregates within the grading range of SMA-10 and finding out the suitable gradation [9]. In summary, based on the research results of previous scholars, this paper aims to optimize the design of thin-layer overlays used in cold regions, study the optimal gradation within the grading range of SMA-10 under dry process, and provide useful reference for the selection of material and process of thin-layer overlay material used in cold regions.

## 2. TEST MATERIALS

### 2.1 Minerals

Crushed limestone was taken as coarse aggregates [10] in this study, the limestone has clear edges and corners and obvious textures. The fine aggregates were the chips of the crushed limestone mined from the quarry, the chips were clean, dry, and pure. The mineral powder was the fine powder of limestone grinded by grinder, the fine powder was gray-white, dry, and loose. All these materials were in line with the requirements of coarse and fine aggregates and fillers stipulated by the *Technical Specification for Construction of Highway Asphalt Pavements* (JTGF40-2004) (hereinafter referred to as the "Specification") [11].

### 2.2 Asphalt

The research objective of this paper is to improve the applicability of thin-layer overlays in cold regions, so the No. 90 asphalt was taken as the matrix for the preparation of RP-modified asphalt by the dry and wet processes [12], and the mixing amount of RP was 10%.

### 2.3 Admixtures

After pre-grinding, 80 mesh RP was adopted in the experiment, the powder was black in color, there's no caked or melted powder in the sample, and it accounted for 10% of the total mass of asphalt. This study also chose lignin fiber [13] in the experiment, which can adsorb light components, toughen the mixture, and enhance its high-temperature shear resistance. No agglomeration or moisture had been observed in lignin fiber, and its mixing amount was 0.3% of the total mass of asphalt mixture. The properties of RP and fiber were all in line with the requirements of the Specification.

## 3. DESIGN OF THE TESTS

Tests conducted in this study were composed of three stages: in the first stage, asphalt experiment was performed to compare the performance of the RP-modified asphalt prepared by the dry and wet processes and then the modification process that is suitable for thin-layer overlays used in cold regions was determined; in the second stage, five groups of gradation design were carried out to find the most suitable gradation for thin-layer overlays; the third stage combined the results of the first two, at this stage, low-temperature splitting test and Cantabro raveling test were conducted to verify the low-temperature crack resistance and disintegration resistance of the proposed material, and its surface skid resistance was measured based on two parameters BPN and MPD, and the gradation that can balance the strength and skid resistance was selected.

### 3.1 Asphalt experiment

In the experiment, RP-modified asphalt samples were prepared by both the dry and wet processes. In the dry process, the matrix asphalt was heated to 175℃ and then 10% RP was added and stirred in the same direction for 300 times, the temperature was kept for 30 minutes for further swelling, and the test pieces were prepared after the sample had fully developed. In the wet process, the matrix asphalt was heated to180℃ and then 10% RP was added, after that, the sample was processed in a high-speed shearing machine at 4500r/min for 60 minutes, and placed in an oven at 170℃ and developed for 45 minutes, afterwards, test pieces were prepared from the sample, and Figure 1 shows the photos of the RP-modified asphalt samples prepared by the dry and wet processes. According to the *Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering* (JTG E20-2011) (hereinafter referred to as the Test Methods) [14], in this study, the performance of the RP-modified asphalt prepared by dry and wet processes was evaluated via the asphalt penetration test (T0604-2011), the asphalt ductility test (T0605-2011), and the asphalt softening point test (T0606-2011).

(a) RP-modified asphalt prepared by dry process (b) RP-modified asphalt prepared by wet process

**Figure 1.** RP-modified asphalt samples

### 3.2 Gradation design

The semi-open SMA gradation shows good comprehensive performance when applied to pavement engineering, but for the SMA-10 gradation that meets the requirements of thin-layer overlays, the Specification gives a 28%-60% range of minerals passing through the 4.75mm sieve mesh, which was relatively wide and had added some difficulties for the design of the SMA-10 gradation [15]. In the experiment, 5 kinds of passing rate at equal intervals were selected, and the gradation of other particle size was adjusted in the same way to attain the five groups of mineral gradation, A, B, C, D and E, and their respective curves are given in Figure 2.

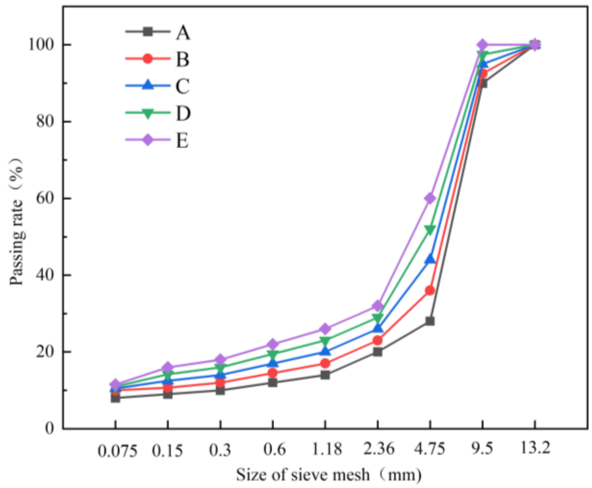


**Figure 2.** Asphalt mixture gradation curves

### 3.3 Asphalt mixture experiment

Procedures of RP-modified asphalt mixture prepared by dry process were: the pre-heated coarse aggregates were put into a mixing pot and stirred for 90s → 80 mesh RP was added and stirred for 90s → No. 90 matrix asphalt and fiber were added and stirred for 90s → fine aggregates and mineral powder were added and stirred for 90s → the materials were cured for 30min and then prepared into test pieces. During this process, in order to let the fiber and RP fully swell and develop in the asphalt, it's required that the fiber and RP should be uniformly dispersed in the mixture so that they could fully interact with the asphalt.

The mixture was subject to asphalt splitting test (T0716-2011) to evaluate its low temperature crack resistance; the experiment temperature was -10℃±0.5℃, and the loading rate was 1 mm/min. Also, the mixture was subject to Cantabro raveling test to evaluate its disintegration resistance. As for the skid resistance of the road surface, MPD was used to indicate it macroscopically, and BPN was used to indicate it microscopically; to measure the two parameters, an electric sand-paving meter and an intelligent pendulum friction coefficient meter were adopted in the experiment. Compared with manual sand-paving meter and the ordinary pendulum friction coefficient meter, these two devices are less affected by human factors and their measurement results are more accurate.

## 4. ANALYSIS OF TEST RESULTS

### 4.1 Asphalt experiment

The test results of the three major indicators of RP-modified asphalt prepared by dry and wet processes are shown in Table 1. All indicators had reached the performance requirements of RP-modified asphalt stipulated by the Specification, however, in real engineering practice, the compatibility between RP and asphalt is poor when RP is taken as modifier, and segregation is likely to occur during transportation and construction. Therefore, in terms of the applicability in long-term low-temperature environment in cold regions, the dry process has a greater advantage, and its merits of "use right after mixed" has well solved the segregation problem and effective reduced the damages of road surface caused by uneven material properties. For this reason, this paper chose the RP-modified asphalt prepared by dry process as the bonding material of thin-layer overlays in cold regions, and the research conducted below was all based on the dry-processing method.

**Table 1.** Three major indicators of RP-modified asphalt prepared by dry and wet processes

| Asphalt | Penetration /0.1mm/25℃ | Ductility /cm/5℃ | Softening Point /℃ |
|---|---|---|---|
| RP-modified asphalt prepared by dry process | 76 | 58 | 51.6 |
| RP-modified asphalt prepared by wet process | 65 | 51 | 65.3 |
| Requirement of the Specification | 60-80 | ≥40 | ≥50 |

### 4.2 Asphalt mixture experiment

4.2.1 Low-temperature splitting test

According to the experimental results shown in Figure 3, as the mixture became finer as a whole, its splitting tensile strength at low temperature showed a trend of increasing first and decreasing later. In terms of the interface damaged by splitting, there're several large particles of broken aggregates on the fractured interface of group A; as for groups B and C, the broken particles were fewer; while for group D, broken aggregate particles were rarely seen. The low-temperature splitting tensile strength consisted of two parts, one part was the imbedding/squeezing force and friction force formed between the coarse aggregates, and the other part was the cohesive force of mastic mortar composed of asphalt, fine aggregates, and mineral powder. For group A, the content of fine aggregates in the gradation was small, the tensile strength was mainly provided by the imbedding/squeezing force and friction force of the coarse aggregates and the inherent strength of the aggregates, the provided cohesive force was relatively weak, so the failure form was mainly brittle failure, and the tensile strain at failure was small; as for groups D and E, the content of fine aggregates had been increased significantly, which had weakened the overall skeleton structure, compared with group C which had a structure with imbedding/squeezing strength, the material's ability to resist tensile force decreased, the deformation at tensile failure increased, and the excessive fine aggregates had an adverse effect on the high-temperature performance of the mixture, during the high-temperature summer time in cold regions, it could result in irreversible damages such as rutting deformation and displacement. Thus, judging from strength and applicability, the two kinds of gradation shown in groups B and C are more reasonable choices.

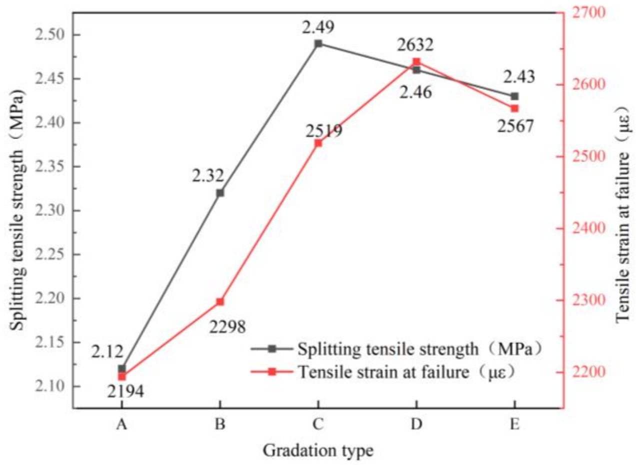


**Figure 3.** Low-temperature splitting test

4.2.2 Cantabro raveling test

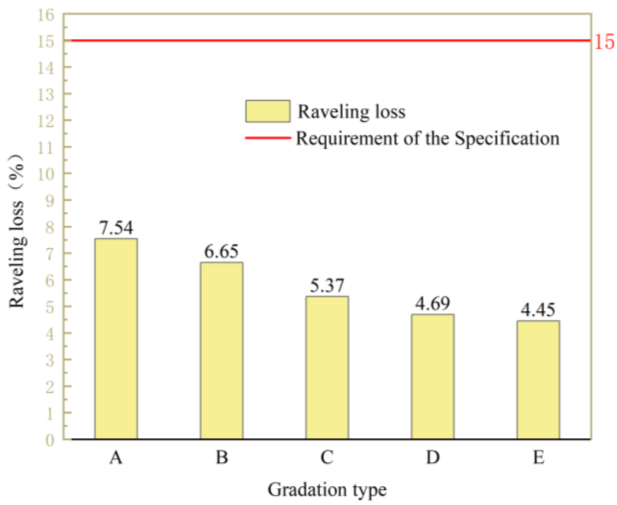


**Figure 4.** Raveling loss of Cantabro test

According to Figure 4, as the gradation of asphalt mixture became finer, the raveling loss decreased gradually, which was because that the mixture became denser and the adhesive property became stronger as the content of coarse aggregates decreased and the content of fine aggregates increased, so the material's ability to resist disintegration had been enhanced. Disintegration resistance is not only related to the binding strength, but also related to the gradation of the material. For the Marshall test pieces with coarser gradation, due to stress concentration, the coarse aggregates exposed on the edges were knocked off at first, then at the newly-exposed fracture, stress would concentrate on it in the next-round of impact, under the conditions of the same size of impact force and the same number of times, mixture with finer gradation gradually exhibited an appearance of being rounded, showing more stable properties and a stronger ability to resist disintegration, however, under any gradation condition, the raveling loss had met the requirements of disintegration resistance of modified asphalt stipulated by the Specification.

### 4.3 Skid resistance of the pavement

According to Figure 5, as the gradation became finer, both BPN and MPD decreased, and groups D and E could no longer meet the requirements in terms of MPD, it's because as the gradation became finer, the mastic mortar formed by asphalt, fine aggregates, and mineral powder occupied a large proportion in the mixture, the coarse aggregates were distributed within it and rarely exposed on the surface of the asphalt pavement to provide resistance to skid, therefore, judging based on the evaluation of the skid resistance of the mixture, the two types of gradation shown in groups D and E couldn't meet the requirements of thin-layer overlays used in cold regions.

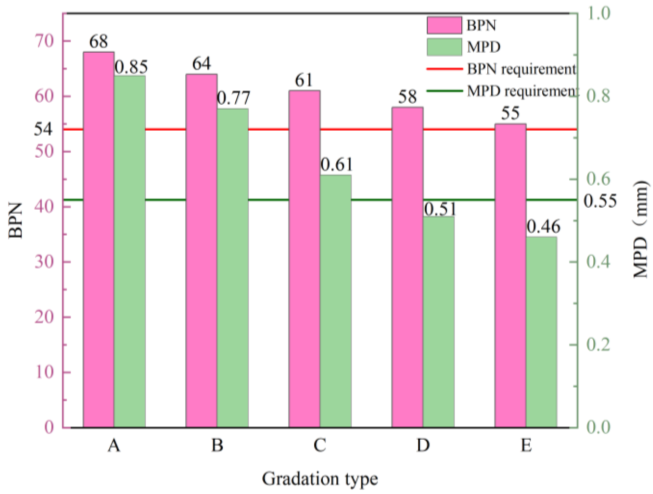


**Figure 5.** BPN and MPD

## 5. CONCLUSIONS

This study made selections of suitable modification process via asphalt test, and attained optimal gradation through the screening of asphalt mixture experiment and skid resistance experiment. The test results obtained in this study are:

1) The study measured three major indicators of RP-modified asphalt (RP content 10%) prepared by dry and wet processes and analyzed the test results: for RP-modified asphalt test pieces prepared by both methods, the three major indicators had all met the requirements of RP-modified asphalt stipulated by the Specification, but in real engineering practice, inevitable factors such as the construction interval might cause serious segregation to RP-modified asphalt prepared by wet process, which can result in damages to the road surface. Therefore, ultimately, the dry process had been selected as the method for modifying the asphalt of thin-layer overlays and preparing the binding materials.

2) By adjusting the proportion of minerals within the grading range of SMA-10 gradation, and performing low-temperature splitting test and Cantabro raveling test on the RP-modified asphalt mixture prepared by dry process, finally, it's determined that medium gradation and medium-coarse gradation had good low-temperature crack resistance, low temperature deformation resistance, and disintegration resistance.

3) According to the test results of BPN and MPD, as the gradation became finer, the two parameters both showed a decline, and the MPD decreased faster; combining with the test results of the strength of asphalt mixture, finally, based on the dry-process RP modification conditions, two kinds of SMA-10 gradation (medium gradation and medium-coarse gradation) had been selected as the gradation of asphalt mixture used for thin-layer overlays in cold regions, and the performance of the proposed material could meet the requirements of strength and usability.

## ACKNOWLEDGMENT

Science and Technology R & D project of China Communications Group (ZJLJ-2018-37).

## REFERENCES


[1] Koohmishi, M., Palassi, M. (2015). Evaluation of application of thin hma overlay on the existing flexible pavement for high-traffic-volume rural highways. Periodica Polytechnica Civil Engineering, 59(1): 65-75. https://doi.org/10.3311/PPci.7128

[2] Rahman, M., Vargas-Nordcbeck, A. (2021). Structural performance of sections treated with thin overlays for pavement preservation. Transportation Research Record, 2675(8): 382-393. https://doi.org/10.1177/0361198121997816

[3] Warid, M.N.M., Hainin, M.R., Yaacob, H., Aziz, M. M.A., Idham, M.K. (2014). Thin cold-mix stone mastic asphalt pavement overlay for roads and highways. Materials Research Innovations, 18(sup6): S6-303. https://doi.org/10.1179/1432891714Z.000000000972

[4] Wang, L., Xing, Y.M., Chang, C.Q. (2012). Experamental study on temperature characteristic of compound crumb rubber modified asphalt and mixture. In Advanced Materials Research, 446: 3647-3651. https://doi.org/10.4028/www.scientific.net/AMR.446-449.3647

[5] Zhang, Y.S., Li, Q.L., Dong, J.Z., Zhang, Q.H. (2014). Study on performance of rubber powder modified asphalt mixture. In Key Engineering Materials, 599: 252-256. https://doi.org/10.4028/www.scientific.net/KEM.599.252

[6] Duarte, G.M., Faxina, A.L. (2021). Asphalt concrete mixtures modified with polymeric waste by the wet and dry processes: A literature review. Construction and Building Materials, 312: 125408. https://doi.org/10.1016/j.conbuildmat.2021.125408

[7] Quintana, H.A.R., Noguera, J.A.H., Bonells, C.F.U. (2016). Behavior of gilsonite-modified hot mix asphalt by wet and dry processes. Journal of Materials in Civil Engineering, 28(2): 04015114. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001339
[8] Radeef, H.R., Abdul Hassan, N., Abidin, A.R.Z., Mahmud, M.Z.H., Yusoffa, N.I.M., Idham Mohd Satar, M.K., Warid, M.N.M. (2021). Enhanced dry process method for modified asphalt containing plastic waste. Frontiers in Materials, 247. https://doi.org/10.3389/fmats.2021.700231
[9] Deng, H.B., Ma, X., Deng, D.Y., Le, T. (2019). Fatigue properties of rubber modified SMA asphalt mixture. In MATEC Web of Conferences, 275: 04001. https://doi.org/10.1051/matecconf/201927504001
[10] Li, J., Wang, Z., Jia, M. (2021). Comprehensive analysis on influences of aggregate, asphalt and moisture on interfacial adhesion of aggregate-asphalt system. Journal of Adhesion Science and Technology, 35(6): 641-662. https://doi.org/10.1080/01694243.2020.1816792
[11] (2004). The ministry of communications highway science institute. Technical code for construction of highway asphalt pavement. Industry Standard-Transport.
[12] Hou, Y.P. (2019). Preparation of SBS modified emulsified asphalt in high cold region. In MATEC Web of Conferences, EDP SCIENCES, 275: 04004. https://doi.org/10.1051/matecconf/201927504004
[13] Khater, A., Luo, D., Abdelsalam, M., Yue, Y., Hou, Y., Ghazy, M. (2021). Laboratory evaluation of asphalt mixture performance using composite admixtures of lignin and glass fibers. Applied Sciences, 11(1): 364. https://doi.org/10.3390/app11010364
[14] (2000). The ministry of communications highway science institute. Highway engineering asphalt and asphalt mixture test procedures. Industry Standard-Transport.
[15] Guo, M., Tan, Y., Du, X., Wen, R., Zhang, M. (2018). A brief review for SMA pavements in China. In transportation research congress 2016: Innovations in Transportation Research Infrastructure. Reston, VA: American Society of Civil Engineers, 305-311.