Performance of Granite Asphalt Mixture Modified by Silane Coupling Agent

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Abstract. In order to improve pavement performance of granite asphalt mixture, the surface of granite mineral powder was organic modified by silane coupling agent. The water stability and high temperature stability of the asphalt mixture were analyzed by Marshall tests, immersion Marshall test, freeze-thaw splitting test and rutting test. The results show that the mixing amount of silane coupling agent in the range from 0.5% to 2.5% can significantly improve the high temperature stability and water stability of the asphalt mixture. Taking into account the performance and economic factors, 2.0% silane coupling agent on the surface of granite filler was recommended.

1. Introduction
Weihai is located in Shandong Province which is riched in granite and diorite. Due to the role of the ocean, the weather of rain or snow happened more than other areas in Shandong Province, the water stability requirements of the pavement are higher. Choose local granite mineral powder as filler of asphalt mixture, it is difficult to guarantee the water stability of the granite mineral powder as the filler of asphalt mixture, because of granite as a typical acidic material, and asphalt adhesion is poor. Experts and scholars at home and abroad in recent years, also the application of acidic stone in asphalt mixture was carried out by research, such as adding antistripping agent, the use of hydrated lime to replace some or all of the mineral powder, improved results have been achieved, but still happened a serious water damage of asphalt pavement [1, 2]. The improvement of the performance of the acid stone asphalt mixture is still an important issue. In this paper, the principle of modification of inorganic filler in the field of polymer materials. Using the modification mechanism of silane coupling agent [3], which make the inorganic surface organic matter of granite, thereby improving the compatibility with the asphalt organic surface with the asphalt adhesion [4].For granite stone road construction in the future of our country provides practical guidance to the use of the mass.

2. Composition of asphalt mixture
70-A road asphalt was selected, asphalt technology test results were shown in Table 1. Aggregate are made of granite gravel in Weihai, fine aggregate selection of natural sand and granite stone, filler selection of granite mineral powder. The apparent density of the filler was 2.73 g · cm\(^{-3}\), the water content was 0.1% and the hydrophilic coefficient was 0.7. According to the relevant test procedures to test the physical and mechanical indicators of aggregate in Table 2, its performance are to meet the technical requirements of the specification [5].Silane coupling agent KH-550 as a modifier, it is amino functional silane, was alkaline, the appearance of colorless or yellowish transparent liquid, versatile,
soluble in organic solvents.

**Table 1.** Technical indexes of 70-A road asphalt.

| Types of asphalt       | Penetration of 25 degrees centigrade /0.1mm | Penetration index | Softening Point /°C | Ductility of 5 degrees centigrade/cm | Density of 25 degrees centigrade (g·cm⁻³) |
|------------------------|---------------------------------------------|-------------------|---------------------|--------------------------------------|------------------------------------------|
| Matrix asphalt         | 71                                          | -0.86             | 47.0                | >100                                 | 1.038                                    |
| Skills requirement     | 60~80                                       | -1.50~+1.00       | ≥46                 | ≥100                                 | Recorded records                         |

**Table 2.** Physical and mechanical indexes of coarse aggregate.

| Crushed stone value (%) | Los Angeles abrasion loss (%) | Polished stone value /BPN | Sturdiness/% | Apparent density (g·cm⁻³) |
|-------------------------|-------------------------------|---------------------------|--------------|---------------------------|
| 17.9                    | 18.6                          | 48                        | 3.6          | 2.73                      |

3. **Molecular structure and mechanism of silane coupling agent**

Silane coupling agent is a class of molecules containing both organic functional groups (Y group) and hydrolyzable inorganic functional groups (X group). The typical molecular structure is shown in Figure 1.

![Figure 1. Schematic diagram of typical silence coupling agent.](image)

Silane coupling agent modification of inorganic fillers is using the theory of chemical synthesis, the silane coupling agent forms a chemical bond with the active group on the surface of the material, the X group hydrolyzed into silanol alcohol with water layer attached to the surface of the granite mineral powder, Silanol alcohol forms hydrogen bonds with hydroxyl groups on the surface of granite mineral powder, but the silicon-hydroxy would condense to lose water and form covalent bond of dry curing, so that the surface of the granite mineral powder to form a coupling layer and its surface organic modification [6]. Coupling layer block water immersion asphalt and stone interface, thus raising the granite water damage resistance of asphalt mixture.

4. **Granite mineral powder surface modification method**

Using the pretreatment of the modified method, not only the amount of coupling agent is small, and the silane coupling agent is distributed more uniformly on the surface of the material. In this paper, the quality of silane coupling agent is 0.5%, 1.0%, 1.5%, 2.0% and 2.5% of the mineral powder. Modified granite mineral powder by wet process, choose water and ethanol as solvent, the effect of the coupling agent was better when the ratio of silane coupling agent, ethanol and water was 5:45:50, through comparative tests. According to the corresponding proportion, adding the silane coupling agent to the solution of water and ethanol, stirred uniformly, the mixed solution is stirred at room temperature for 20min. Through comparing the test, taking into account the effect of coupling agent modification, economy, practical operation, the optimum operating conditions are that the rotational speed of cement glue sand mixer is 140r/min, total stirring time was 1.5h, and every 300 seconds pause 20 seconds, after mixing the mixture was dried in a 90°C oven for 3 hours. To provide a reference for modification process of silane coupling agent modify inorganic fillers in the future. The granite mineral powder was introduced into the mixing pan, and the machine was started. After stirring for 5 seconds, the diluted silane coupling agent solution was added slowly while stirring, coupling agent in 20s ~ 30s plus finished, after completion of the stirring, the mixture was dried in a 90°C for 3 hours [7].

5. **Road performance test of modified granite mineral powder asphalt mixture**
5.1 Mix proportion design of modified granite mineral powder asphalt concrete
AC-16 asphalt mix was used in the experiment [8]. Graphic design to obtain mineral aggregate with the ratio of 10~20mm: 5~10mm: natural sand: stone chips: mineral powder = 19: 44: 18: 13: 6. With the Marshall test, the optimum bitumen aggregate ratio is 4.6%.

5.2. Flooding Marshall test
According to the requirements of JTG E20-2011, the water stability of the mixture was evaluated by the residual stability of the Marshall test and the freeze-thaw splitting strength ratio of freeze-thaw splitting test. Immersion Marshall test using 6 groups of different silane coupling agent content of the comparative test (silane coupling agent content of 0% to 2.5% of the modified granite filler), the test results in Table 3.

| The amount of silane coupling agent /% | Stability /KN | Residual stability /% |
|--------------------------------------|---------------|-----------------------|
|                                      | 0.5h          | 48h                   |                       |
| 0.0                                  | 10.45         | 8.21                  | 78.6                  |
| 0.5                                  | 12.62         | 10.25                 | 81.2                  |
| 1.0                                  | 14.78         | 12.50                 | 84.6                  |
| 1.5                                  | 15.56         | 13.80                 | 88.7                  |
| 2.0                                  | 16.20         | 14.48                 | 89.4                  |
| 2.5                                  | 14.42         | 12.78                 | 88.6                  |

It can be seen from Table 3 that the silane coupling agent with 0.5% ~ 2.5% content can improve the surface properties of the granite mineral powder [9], in which the silane coupling agent content is 2.0 %. The modification effect of granite filler is the most prominent. Compared with the asphalt mixture with unmodified granite filler, the Marshall stability, immersion Marshall stability and residual stability are significantly improved.

5.3. Freeze-thaw splitting test
The standard Marshall specimens were subjected to splitting tests under normal conditions and freeze-thaw cycles, respectively, and the residual strength ratios of the freeze-thaw splitting tests were calculated. The test results are shown in Table 4.

| The amount of silane coupling agent /% | Void ratio /% | Splitting strength before freezing and thawing /MPa | Splitting strength after freezing thawing /MPa | Freeze-thaw splitting strength ratio /% |
|---------------------------------------|---------------|-----------------------------------------------------|-----------------------------------------------|----------------------------------------|
| 0.0                                   | 6.1           | 0.86                                                | 0.52                                          | 60.5                                   |
| 0.5                                   | 6.3           | 1.04                                                | 0.81                                          | 77.9                                   |
| 2.0                                   | 6.5           | 1.07                                                | 0.92                                          | 86.0                                   |
| Skills requirement                    | –             | –                                                   | –                                             | >75.0                                  |

It can be seen from Table 3 and Table 4 that the asphalt mixture without silane coupling agent does not meet the water stability requirements of asphalt mixture in wet areas such as Weihai [10]. When the
dosage of silane coupling agent is 0.5% and 2.0%, the water stability is not only the requirement, but the TSR value is 17.4% and 25.5% higher than that of the unmodified limestone filler asphalt mixture after freeze-thaw cycle. Indicating that the use of silane coupling agent modified granite mineral powder can significantly improve the performance of asphalt mixture water damage.

5.4  Rutting test
The rutting test results are shown in Table 5.

| The amount of silane coupling agent /% | Displacement of 45 minutes /mm | Displacement of 60 minutes /mm | Dynamic stability / (Times·mm⁻¹) |
|--------------------------------------|-------------------------------|-------------------------------|---------------------------------|
| 0.0                                  | 5.20                          | 5.834                         | 994                             |
| 0.5                                  | 5.022                         | 5.553                         | 1186                            |
| 2.0                                  | 4.642                         | 5.154                         | 1230                            |

From the Table 5 can be shown that compared with the unmodified granite mineral powder, the dynamic stability of the asphalt mixture with silane coupling agent modified granite mineral powder was increased by 19.3% and 23.7%. The high temperature stability of the asphalt mixture with modified granite mineral powder is significantly improved.

6. Conclusions
(1) To improve high temperature stability and water stability of the asphalt mixture synthesized, the amount of the coupling agent 2.0% was recommended by using the silane coupling agent.
(2) Compared with the unmodified granite mineral powder, the residual stability of the asphalt mixture increased by 10.8% and the freeze-thaw splitting strength ratio increased by 25.5%, the dynamic stability increased by 23.7%. Silane coupling agent modified granite mineral powder significantly improved the pavement resistance of asphalt mixture and other pavement performance.
(3) The modification of granite mineral powder by silane coupling agent, not only achieves the road performance requirement of the asphalt mixture with granite mineral powder as filler, but also significantly improved the water resistance of the asphalt mixture. So that rich granite stone Weihai area to make use of local materials, and granite mineral powder as filler of asphalt mixture has extended significance and economic benefits.

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