# Rubber-Cement Stabilized Gravel Base Road Performance

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**Abstract.** In order to study the road performance of rubber-cement stabilized gravel base, the road performance of rubber-cement stabilized gravel base is explored through different amount of rubber powder, mechanical properties of different cement dosage and crack resistance performance index. The apparent morphology of the specimen was tested by scanning electron microscope, and the structural characteristics and adhesion characteristics of different cement mixture and different rubber powder, the distribution characteristics of rubber powder in the mixture and the influence mechanism of the interface microsurface were analyzed. Through the comprehensive evaluation of mechanical properties, crack resistance and scanning electron microscope results, the results show that the cement hydration products and rubber powder form a mesh structure, which effectively disperse the stress through the network structure during the traffic load. Since the elasticity of rubber powder itself and good high temperature stability, the incorporation of rubber powder can effectively absorb the stress and strain generated by moisture evaporation during dry and temperature shrinkage, and maintain its own properties stable under temperature change, so as to reduce the temperature shrinkage and dry shrinkage coefficient of the mixture and reduce the generation of reflection cracks. In this study, the range of road grade applicable for different mix ratios is given through the unlimited compressive strength, which provides theoretical reference for selecting appropriate mix ratios according to road grade in actual engineering.

**Keywords:** road base; rubber powder; mechanical properties; crack resistance; reflection crack

## 1 Introduction

The road base is the main bearing layer of the road surface, and a good base is the key factor to ensure the road quality and road life. From the classification of the mechanical characteristics of the pavement structure, the pavement base can be divided into rigid


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base, semi-rigid base and flexible base. In China expressway, the semi-rigid base is regarded as an important way of base structure[1].

However, in recent years, the disease problem of semi-rigid base has attracted wide attention both at home and abroad. It is found that one of the biggest problems of the semi-rigid base is the reflection crack produced in the use process. Under the circulation action of traffic load and temperature load, small cracks occur at the pavement base, and then continue to develop into macroscopic cracks. The macroscopic cracks continue to expand over time until the reflection cracks extend to the road surface, and the road surface breaks and destroys[2]. The emergence of reflection cracks not only affects the speed and comfort of driving, but also increases the loss of vehicles, improves the operating cost, and more importantly, poses a serious threat to driving safety, so that the road surface no longer meets the requirements of driving safety, comfort, economic and fast service functions. According to the investigation, if the road reflection cracks are not treated, it will shorten the overall life of the road surface by 10~20%. Meanwhile, if the road with dense reflection cracks is not treated, the accident rate is 1~3% more than the normal road. Therefore, how to inhibit the generation of reflection cracks is particularly critical. People realize that to cure the problem of reflection cracks, we need to start with the material of the road base. Therefore, it is necessary to develop a new pavement base material to optimize the structure of the pavement base and reduce the formation of reflection cracks.

Rubber powder is a kind of has a high elasticity, high damping, strong energy absorption of organic materials, its doping in the pavement base can replace part of the concrete, cement mortar and cement stable gravel mixture of fine aggregate, and to a certain extent can effectively absorb the mixture because of internal stress, enhance the toughness of the mixture, reduce the mixture temperature change stress strain, reduce the deformation of the mixture, to reduce the formation of pavement base reflection cracks. Combining rubber powder into cement stabilized gravel base will reduce or delay road cracking and prolong road life, which will be of great significance to promote the development of national economic construction and social stability[3].

# 2 Trial

## 2.1 Raw Materials

The particle size of coarse aggregate is 20~30,10~20,5~10mm of different graded gravel, the fine aggregate is 0.075~5mm stone powder, the particle diameter of rubber powder is 60 mesh. The technical specifications of cement are shown in Table 1, those of coarse aggregate in Table 2 and those of fine aggregate in Table 3.

**Table 1.** Technical indicators of cement

| | surveillance project | | qualification | detection result |
|---|---|---|---|---|
| 1 | Specific surface area ($m^2$ / kg) | | ≥300 | |
| 2 | Standard consistency of water consumption (%) | | | 28.9 |
| 3 | time of setting | initial set (min) | ≥240 | 292 |

| | | | | |
|---|---|---|---|---|
| | | final set (min) | 360≤x≤600 | 393 |
| 4 | stability | Relip (mm) | <5 | 2.0 |
| | | Try the pie method | | |
| 5 | rupture strength | 3d(MPa) | >3.5 | 5.7 |
| | | 7d(MPa) | | |
| | | 28d(MPa) | >6.5 | |
| | compression strength | 3d(MPa) | >17 | 27.6 |
| | | 7d(MPa) | | |
| | | 28d(MPa) | >42.5 | |

**Table 2.** Technical indexes of the crude aggregate

| order number | surveillance project | | qualification | detection result |
|---|---|---|---|---|
| 1 | Mud content or less than 0.075mm particle content of (%) | | <2 | 0.8 |
| 2 | Mud mass content of (%) | | | / |
| 3 | Needle, sheet particles content | mixture (%) | ≤22 | 18 |
| | | Particle size is greater than 9.5mm in size of (%) | | / |
| | | Grain size is less than 9.5mm (%) | | |
| 4 | crushing value (%) | | ≤26 | 18.6 |

**Table 3.** Technical indexes of the fine aggregate

| surveillance project | | qualification | detection result |
|---|---|---|---|
| water ratio limit | liquid limit (%) | <28 | 24 |
| | plastic limit (%) | | 21 |
| | plasticity index | ≤5 | 3 |

## 2.2 Mechanical Test

The technical indexes of aggregate used in the test meet JTG E42-2005 aggregate Test Regulations for Highway Engineering. On the basis of the recommended range of C-B-3 in JTG / TF 20-2015, use the gradation design in the specification of Superpave, optimize the aggregate grading, reduce the maximum particle size of coarse aggregate, and increase the dosage of intermediate aggregate. The advantage of this grading is strong crack resistance.

According to the vibration compaction test method (T0842-2009), the cement content is set at 3%, 4% and 5%, and the moisture content is set at 3%, 4%, 5%, 6% and 7%. The optimal moisture content and the maximum dry density were determined by the vibration compaction test. According to the optimal water content, the base specified compaction degree of 98% by vibration compaction method Φ150mm 150mm molding cylindrical specimen. Each group formed 13 specimens, and conducted unlimited compressive strength test, compressive rebound modulus test and split strength test for standard maintenance ages of 7d, 14d, 28d, 28d, 60d and 90d. A medium beam specimen of 100mmX100mmX150mm was prepared, 13 specimens were formed under each group, and the bending tensile strength of 7d, 14d, 28d, 28d, 60d and 90d was tested.

### 2.3 Dry Shrinkage Test

Prepare the middle beam specimen with size of 100mm 100mm 150mm according to the production method of stabilizing material specimen of inorganic combination (beam type) (T0844 -2009), form 13 specimens under each group of mix, maintain the specimen standard 7d, measure the initial length of the specimen, smooth the ends of the specimen, paste plexiglass, and fix them on the shrink apparatus, install two micrometers at each end, and put the shrink apparatus with the specimen into the dry shrinkage chamber. After placement, transfer the microdial meter at both ends of the specimen to the middle position, record the value of the micrometer of the specification7d,12d,17d,22d and 28d respectively. After the test, put the specimen in the oven to dry to constant weight.

### 2.4 Temperature and Shrinkage Test

Prepare the middle beam specimen of 100mmX100mmX150mm according to the manufacturing method (beam type) (T0844-2009), form 13 specimens under each group of combination ratio, standard curing 7d, place the specimen in the ventilated and dry place to normal temperature. Before the test, measure the length of the specimen by means of a steel ruler; grinding the glass pieces at the ends; the glass rod is placed on the bottom of the shrink instrument to reduce the friction between the bottom and the shrink instrument, place the specimen on the glass rod with the test surface facing down; the four micrometers are fixed on the shrink instrument, and the reading of the four micrometers is adjusted to about 0.5. Record the specimen together with the contraction instrument in the high and low temperature transformer test box; heat the temperature to the test temperature and keep warm for 3h; record the micrometer reading. The shrinkage degree of the specimen was determined by a certain temperature difference, which was used in the test. Set 5 temperature levels with a temperature difference of 10°C. The difference between the reading and mean of the four thousands and the reading and mean of the four thousands at the previous temperature level is the temperature shrinkage of the specimen.

### 2.5 SEM Test

This study observe the rubber cement stabilized gravel mixture and mainly analyze the dispersion and uniformity degree of rubber. In this test, the mixture of the same cement dosage and different rubber powder was scanned by EM, and 4% cement dosage and the dosage of rubber powder were 0%, 0.5%, 1% and 1.5% respectively. After the surface of the specimen is cleaned with an air jet gun, and the first vacuum extraction is completed, the specimen is sprayed. After the vacuum injection, the specimen is put into the SEM detection box, and the vacuum is treated again, and then the experiment begins. According to the observation in the experiment, the SEM multiple of 500 times is the best observation multiple.

# 3 Test Results and Discussion

## 3.1 Mix Ratio Design

In this mix ratio design study, the cement dose is 3%, 4% and 5%, and the predetermined water content is 3%, 4%, 5%, 6% and 7%. The optimal water content and maximum dry density are determined by vibration compaction method. The optimal moisture content and maximum dry density under different cement content are shown in Table 4:

**Table 4.** Maximum dry density and optimal water content of cement-stabilized gravel

| Cement: gravel | optimum moisture content (%) | Maximum dry density (g/cm$^3$) |
|---|---|---|
| 3.0:100 | 3.6 | 2.256 |
| 4.0:100 | 3.4 | 2.267 |
| 5.0:100 | 3.3 | 2.320 |

## 3.2 Mechanical Properties

***3.2.1 Analysis of the Unlimited Compressive Strength Test.*** The results of the unlimited compressive strength test are shown in Fig 1 to 3:

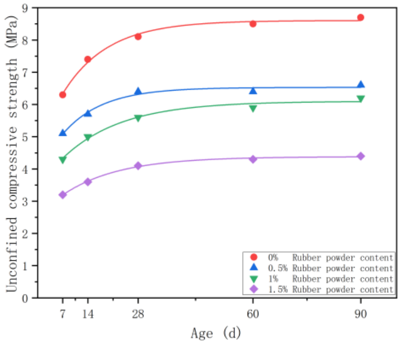


**Fig. 1.** 3% cement content unconfined compressive strength

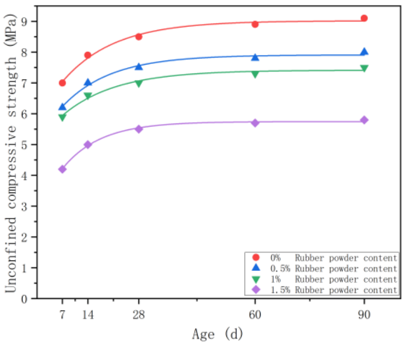


**Fig. 2.** 4% cement content unconfined compressive strength

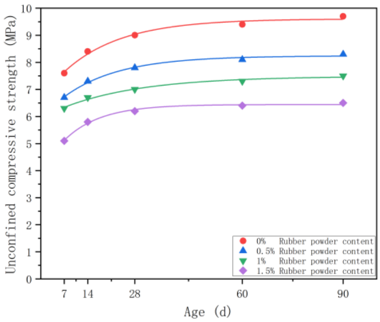


**Fig. 3.** 5% cement content unconfined compressive strength

***3.2.2 Springback Modulus***. The results of compression rebound modulus test are shown in Fig 4~6:

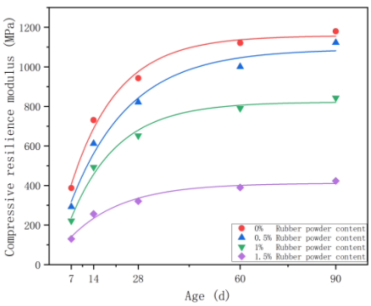


**Fig. 4.** 3% cement content compressive resilience modulus

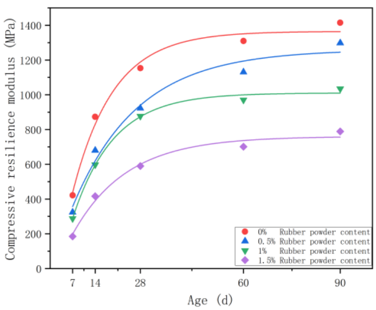


**Fig. 5.** 4% cement content compressive resilience modulus

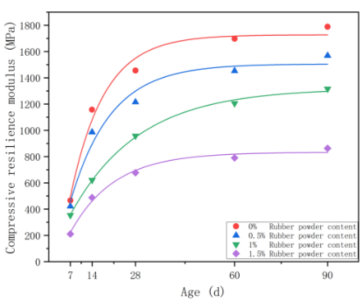


**Fig. 6.** 5% cement content compressive resilience modulus

***3.2.3 Cleavage Strength***. The results of the split strength test are shown in Fig 7~9:

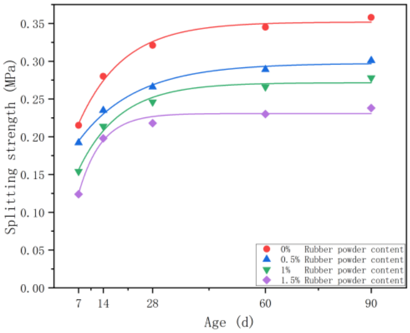


**Fig. 7.** 3% cement content splitting strength

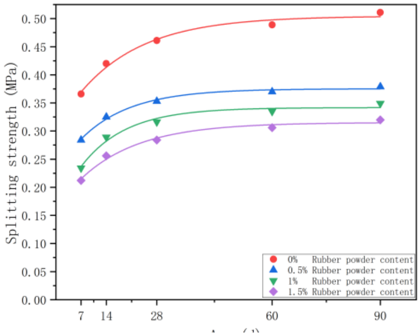


**Fig. 8.** 4% cement content splitting strength

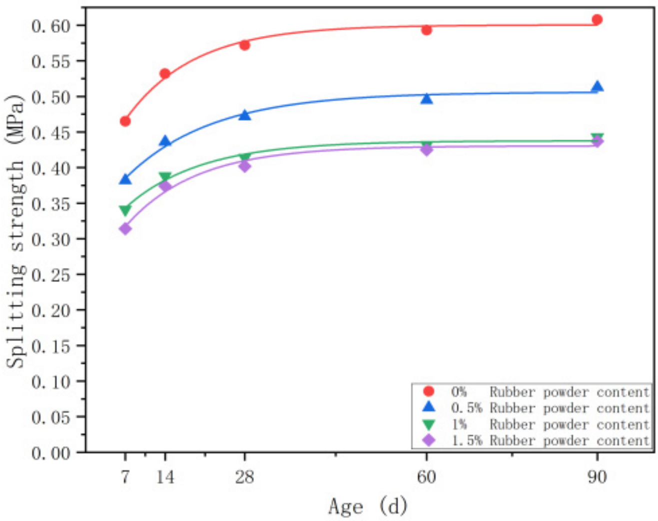


**Fig. 9.** 5% cement content splitting strength

***3.2.4 Bending Tensile Strength***. The bending tensile strength test experiment is shown in Fig Fig 10-12:

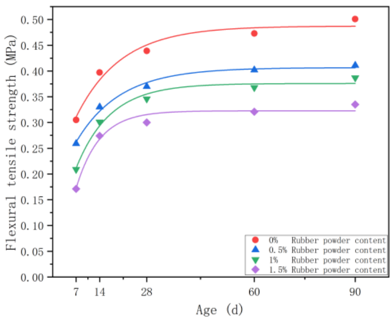


**Fig. 10.** 3% cement content flexural tensile strength

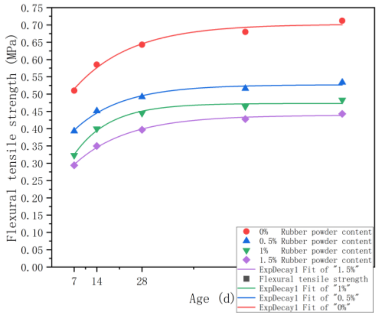


**Fig. 11.** 4% cement content flexural tensile strength

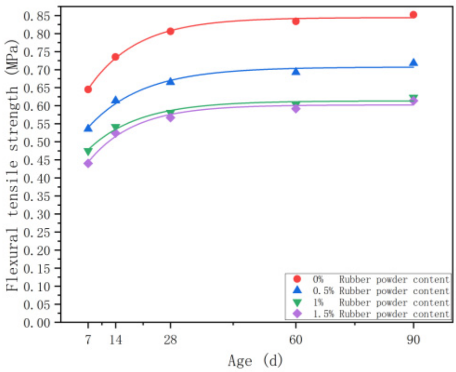


**Fig. 12.** 5% cement content flexural tensile strength

According to Fig 1~12, the following conclusions can be drawn

(1) The mechanical properties of cement-stabilized gravel at the same cement dose and rubber powder dosage increased significantly in the early stage (before 28d). The rate of mechanical properties growth slowed during the age of 28d-60d. In the 60d-90d phase, the improvement in mechanical properties becomes very slow. The variability in the growth rate of mechanical properties is positively correlated with the rate of cement hydration production. Cement hydration reaction is characterized by fast and then slow: in the early stage, the formation rate of hydration products is faster and the cementing ability is also rapidly enhanced; while in the later stage, the formation rate of hydration products is gradually reduced and the improvement rate of cementing ability is slowed down[4]. As can be seen from the unlimited compressive strength that the

dosage of cement plays a vital role in the improvement of the unlimited confined compressive strength. Although the increase of rubber powder will reduce the unlimited compressive strength, the reduction is not large. With the adjustment of the road grade and finding the appropriate mix ratio, the performance can effectively improve the road performance.

(2) Under the same cement dosage condition, the increase of rubber powder dosage leads to a gradual decrease in the mechanical properties of the specimen. The mechanical properties of cement stabilized gravel base mainly come from the internal friction resistance and bonding force between cement mortar and aggregate interface[5]. Due to the physical and chemical differences of rubber powder and cement, the introduction of rubber powder makes the interface structure even weaker[6]. Under compression conditions, such interface weakening may lead to local disruption and thus reduced mechanical properties.

(3) The same amount of rubber powder mixed, cement dose increase, mechanical performance strength gradually increased. Cement is the main cementing material, and when the cement dose increases, the bonding force between the interfaces also increases, and the structure inside the specimen is more stable[7].

## 3.3 Cracking Resistance

***3.3.1 Dry Shrinkage Performance***. The results of shrinkage performance are shown in Fig 13~15:

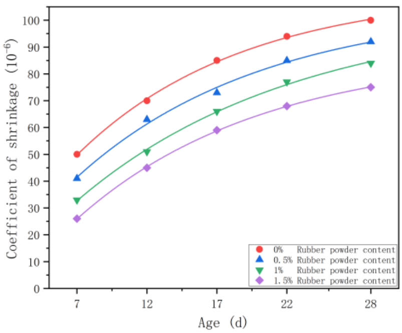


**Fig. 13.** 3% cement content coefficient of shrinkage

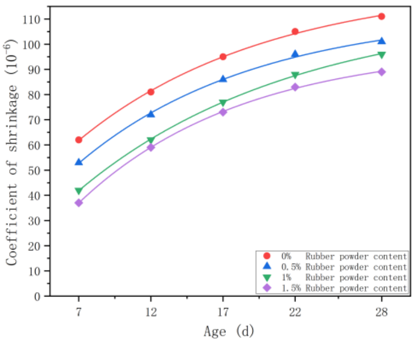


**Fig. 14.** 4% cement content coefficient of shrinkage

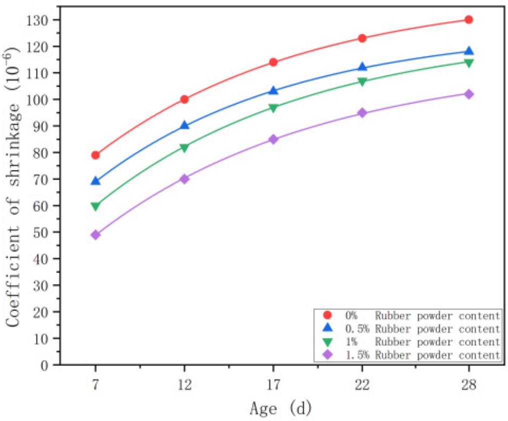


**Fig. 15.** 5% cement content coefficient of shrinkage

From Fig 13 to 15:

(1) At the same cement dose and the same rubber powder dosage, the shrinkage coefficient increases rapidly at 0-12d; at 12-22d, the growth trend of shrinkage coefficient gradually slows down; at 22, the shrinkage coefficient increases very slowly at 22-28d. Early test due to cement hydration rapid evaporation internal moisture and specimens inside the capillary water surface drop lead to the contraction of the material, as the capillary water gradually evaporate, the mixture internal relative humidity gradually decreases, the adsorption of water evaporation, intermolecular force gradually increase, specimen further contraction. With the completion of cement hydration, the internal adsorption water evaporates, the specimen enters the drying period, and the volume shrinkage also tends to be in a stable state[8].

(2) At the same cement dose, with the increase of the amount of rubber powder, the shrinkage coefficient gradually decreases, and the rubber has a certain water absorption. When the specimen occurs water loss, the water absorbed inside the rubber powder slows down the water loss rate of capillaries inside the specimen.

(3) When the same rubber powder is mixed, the cement dose increases, the shrinkage coefficient increases, and the mixing water demand is also increasing, resulting in the dry shrinkage strain increased in the process of cement hydration.

(4) The rubber powder itself has elasticity, which can effectively reduce the tension between the molecules produced in the process of shrinkage deformation, and reduce the formation of reflection cracks in the early stage of shrinkage.

***3.3.2 Temperature and Shrinkage Performance.*** The results of temperature shrinkage performance are shown in Fig 16~18:

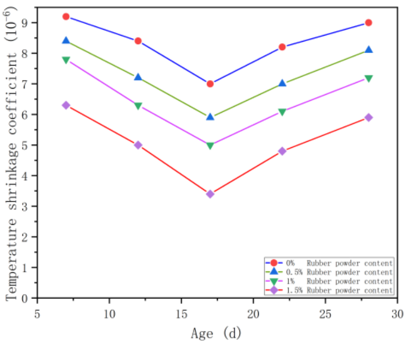


**Fig. 16.** 3% cement content temperature shrinkage coefficient

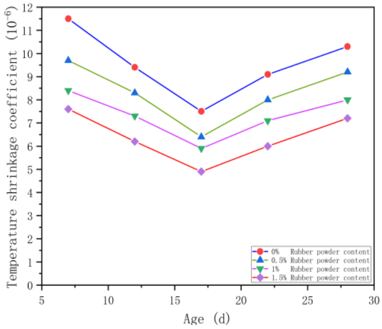


**Fig. 17.** 4% cement content temperature shrinkage coefficient

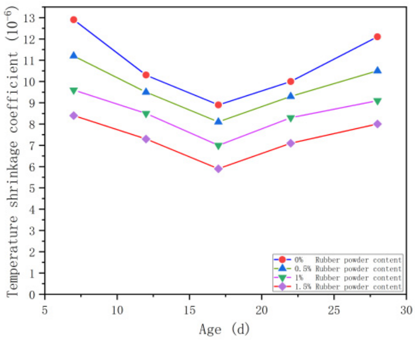


**Fig. 18.** 5% cement content temperature shrinkage coefficient

From Fig 16-18:

(1) At the same cement dosage and rubber powder dosage, the temperature shrinkage coefficient gradually increases with the increase of temperature. At 10~30°C, the temperature shrinkage coefficient decreases at constant speed, and the temperature shrinkage coefficient reaches the lowest point at 0-10°C, while at-10~ 0°C, the temperature shrinkage coefficient increases rapidly. At 0~30°C, the higher the temperature, the faster the moisture evaporation rate inside the specimen, the greater the stress strain, resulting in a larger temperature shrinkage coefficient. With the decrease of the temperature, the evaporation of moisture decreases the increasing trend of the shrinkage coefficient[9].

(2) The same cement dosage, rubber powder incorporation increase, temperature shrinkage coefficient gradually reduced, this is due to the change of temperature, affect the rate of water evaporation, moisture evaporation in the process of stress strain, and

rubber powder due to its elasticity, will absorb the generated in the process of stress, reduce the deformation of the specimen, effectively reduce the formation of reflection cracks[10].

(3) When the same rubber powder is mixed, with the increase of cement dose, the greater the temperature shrinkage coefficient, the increase of cement dose will increase the stiffness, the base modulus also increases, the temperature stress under thermal expansion and cold contraction also increases, the increase of cement dose will be more likely to produce reflection cracks[11].

## 4 Microstructure of the Mixture

The results of SEM microscopic test are shown in Fig Fig 19-22:

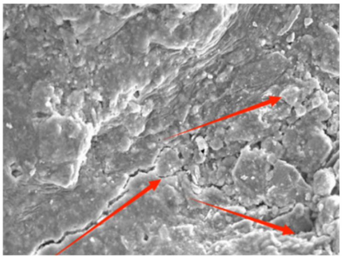

**Fig. 19.** 0% rubber powder content scanning electron microscopy

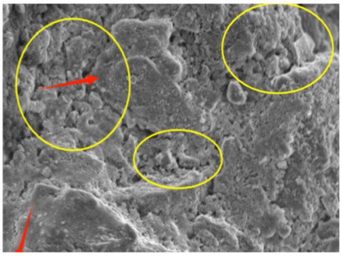

**Fig. 20.** 0.5% rubber powder content scanning electron microscopy

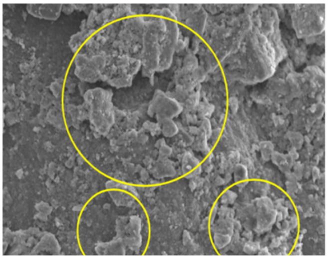

**Fig. 21.** 1% rubber powder content scanning electron microscopy

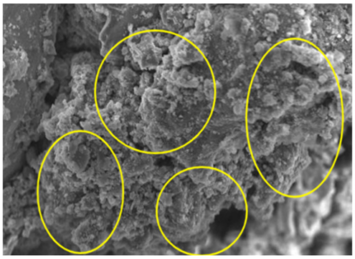

**Fig. 22.** 1.5% rubber powder content scanning electron microscopy

In this experiment, scanning electron microscope was used to analyze the rubber-cement stabilized gravel mixture, and observe the characteristics of the specimen under a magnification of 500 times. The red arrow in the Fig refers to the crack expansion direction, and the rubber powder in the yellow area. The following conclusions are obtained:

Test block surface without rubber powder is smooth, no rubber powder adhesion, cement hydration reaction, together the aggregate depends on the adhesive of cement hydration products, cement stabilized gravel test is the cement adhesive, poor cement flexibility, rigid, brittle, external load, stress concentration, from the aggregate adhesive first cracking; because this test is crack resistant grading, from the skeleton under most of the bearing capacity, with increasing pressure, the red arrow in the Fig is the crack expansion direction.

Mixed rubber powder after the test block surface slightly uneven, smooth part reduced, the yellow area for rubber powder and cement, rubber powder filled with the mesh structure, because the rubber powder is elastic, when rubber powder filled the gap between the cement and the aggregate, can effectively reduce the formation of reflection cracks, but due to the amount of mixed rubber powder is limited, cant give full play to the flexibility of rubber powder, part of the combination of no rubber powder, still produce fine cracks.

With the further increase of the rubber powder blending amount, The rubber powder has filled the gap between the cement and the aggregate, In the yellow area is the rubber powder, And because when mixing, Adopt the method of giving priority of dry mixing with rubber powder and cement, The rubber powder surface is covered with cement, So that the poor adhesion of the rubber powder can be used in the cement hydration, Effective adhesion to the aggregate surface, The hydration products of the cement interweave with the rubber powder, Forming a dense network of the structure; The elasticity of the rubber powder effectively dispersed the stress, And in the mixture and cement and aggregate formed a better stress transfer chain; At the same time, the rubber powder is not dense in the interface, Limited reduction in the intensity, But the increase in flexibility and elasticity, Effectively enhance the ability of the specimen to resist temperature shrinkage and dry shrinkage, Effectively reduce the formation of reflection cracks, Obviously the advantages of rubber powder outweigh the disadvantages[12].

## 5 Conclusion

In this study, the following conclusions were obtained by detecting the mechanical properties, dry shrinkage and temperature shrinkage properties and microscopic SEM:

From the microscopic point of view, with the increase of the amount of rubber powder, the hydration products of cement and rubber powder gradually form a dense mesh structure on the surface of the test block. When the road base is subjected to traffic load, it can effectively disperse stress through these mesh structures, so as to reduce the formation of reflection cracks.

(2) Rubber powder, as a material with good thermal stability, has high stability between-50°C and 120°C. When it is mixed into the road base, the rubber powder is stable within the conventional temperature difference range, which can also effectively improve the reflection cracks produced by the traditional semi-rigid base in the temperature change.

(3) Due to the high cement content, the overall stiffness is large, it is easy to produce reflection cracks when the load and temperature difference; and mixed with rubber

powder, can effectively reduce the dry shrinkage, temperature shrinkage value, so as to reduce the formation of reflection cracks.

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