Study on the Performance of Road Cement Stabilized Base Using Natural Graded Gravel

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Abstract. In order to alleviate the increasing supply shortage of building materials, this paper uses the method of comparative test to carry out a stability study of cement stabilized base with green cement bonded natural graded gravel on compressive strength, splitting strength, resilient modulus and other indicators. The research shows that the natural grade gravel, which is a kind of energy-saving and environmental natural building materials, has good road performance as a raw material for cement stabilized base with green cement binding. The green cement bonded base shows higher compressive strength, splitting strength and resilient modulus than those of ordinary Portland cement.

1. Introduction
Construction industry is a high energy consumption industry. With the development of infrastructure construction, the demand for raw building materials is increasing day by day, which leads to over-exploitation of natural resources and causes excessive consumption of natural resources, ecological environment damage and other environmental problems. The state has come up corresponding policies to encourage the research and application of green building materials instead of natural minerals. Natural graded gravel is a common raw material in Xinjiang area, which is composed of pebble, sand and soil. The pebbles in the natural gravel have good carrying performance, the sand, soil and other fine aggregates make the structure compact and lead to high carrying capacity and low porosity. The correct and reasonable use of natural grade gravel can not only improve the current situation of shortage of building materials, but also realize the local materials of building materials, reduce the cost of construction and promote the sustainable development of highway engineering construction.

Traditional cement could not bind the natural graded gravel well for the high soil content. In this study, cement stabilized base using natural graded gravel was fabricated by adding a new type of cementitious materials call green cement. This kind of material could bind the fine particles on the soil surface to generate gel material at room temperature to solidify the structure. The main components of this material are CaO, SiO\textsubscript{2}, Al\textsubscript{2}O\textsubscript{3}, Fe\textsubscript{2}O\textsubscript{3} and activator. The composition could be adjusted to show different adaptive performance which could be able to bind construction waste, industry waste slag and etc. Compared with traditional cement, the concrete fabricated with this kind of cementitious material have higher strength, lower cost and shorter construction time.
2. Raw materials

2.1. Cement
Ordinary Portland cement 42.5 and green cement 42.5 were used as binder material. In accordance with the test specifications of the standard consistency, the water consumption, initial coagulation time, stability and strength of two cements were measured. The test data are shown in Table 1:

| Test projects                      | Green Cement | Ordinary Portland Cement | Specification values |
|-----------------------------------|--------------|--------------------------|----------------------|
| Standard Consistency (%)          | 137          | 151                      | /                    |
| Initial condensation time (min)   | 192          | 150                      | ≥45                  |
| Final condensation time (min)     | 252          | 180                      | ≤600                 |
| Stability                         | Qualified    | Qualified                | Qualified            |
| Fineness (%)                      | 6.22         | 9.89                     | <10                  |
| Flexural Strength (MPa)           | 4.3          | 3.5                      | ≥2.5                 |
| Compressive strength (MPa) 3d     | 30.5         | 25.2                     | ≥10                  |
| Flexural Strength (MPa) 28d       | 7.8          | 6.6                      | ≥6.5                 |
| Compressive strength (MPa) 28d    | 51.9         | 45.9                     | ≥42.5                |

2.2. Natural grade with gravel
The natural grade gravel selected in the experiment is the typical natural grade gravel in Hami area. Sieving test was carried out for No. 1 and No. 2 natural grade gravel which were taken from 2 road construction site in Hami. The sieving test was carried out according to Communication Industry standard (JTJ034-2000). Table 2 showed the screening data of 2 type of raw materials.

| Sieve hole size (mm) Grading Range | 31.5 | 26.5 | 19  | 9.5 | 4.75 | 2.36 | 0.6 | 0.075 |
|------------------------------------|------|------|-----|-----|------|------|-----|-------|
| Specification                      | 100  | 90~100| 72~89| 47~67| 29~49| 17~35| 8~22| 0~7   |
| 1#                                 | 97.8 | 94.4 | 89.1| 75.5| 63.7 | 54.6 | 43.7| 18.2  |
| 2#                                 | 100  | 100  | 97.0| 87.9| 72.5 | 55.7 | 34.1| 8.2   |

3. Experimental program
The optimal water content of natural graded gravel made cement stabilized base was determined by heavy 98 hit method according to standard T0804-1994. To determine the optimal water content and maximum dry density, the cement content for hit test is 4.5%, and water contents is ranged from 2-8% in accordance with the standard. The specimens for compressive strength test were made in accordance with standard T0843-2009. The test specimens with 150mm diameter and 150mm height were made, then cured in standard condition. The compressive strength, splitting strength and resilient modulus were measured after 7d and 28d curing.

4. Analysis of test results
As shown in Table.1, the performance of ordinary cement met the requirements of the specification and the performance of green cement was better than ordinary cement. The standard consistency water consumption of green cement could save about 10% compared with ordinary cement. The initial condensation time of green cement was 28% and 40% higher than that of ordinary cement. The compressive strength of green cement was 17% higher than ordinary cement, and the flexural strength was increased by 20%. The main reason was that green cement particles were smaller so the hydration reaction with sand was more complete, and the consolidation capacity of cement was maximized. The standard consistency water consumption of green cement was less than that of ordinary 42.5# ordinary cement under the same label. The chemical ion exchange reaction occurred to reduce the water absorption effect caused by capillary, powder voids and surface tension of soil powder. And make the
treated soil powder from "hydrophilic" into "hydrophobic" which directly reduced the water demand greatly.

Data analysis can be seen in Table 2: 1# natural graded gravel was mixed with some large size pebbles, resulting in passing rate of 31.5mm and 26.5mm size was less than the specification value. The particle size of 2# was smaller than 1#. Both of two kinds of material were relatively smaller than standard specification, which were not recommended to be used as raw materials for cement stabilized base with traditional cement.

4.1. Liquid and plastic limit

**Table 3. Liquid plastic limit test results.**

| Aggregate type | Liquid limit (%) | Specification values | Plastic limit (%) | Specification values | Plastic index |
|----------------|------------------|----------------------|------------------|---------------------|--------------|
| 1#             | 19.8             | < 40                 | 14.1             | < 17                | 5.7          |
| 2#             | 19.8             | 12.33                |                  | 17                  | 7.5          |

The liquid limit of 1# and 2# is same for the similar composition of less than 5mm particles in two kinds of natural graded gravels, and the plastic limit of 1# is greater than 2# mainly because the soil content of 1# is 18.2%, which is much higher than the soil content of 2# 8.2%.

4.2. Transcript test

**Figure 1.** The optimal water content and maximum dry density of a) 1# with ordinary cement, b) 1# with green cement, c) 2# with ordinary cement and d) 2# with green cement

**Table 4.** Transcript test results (Cement content 4.5%).

|                        | 1# Ordinary | 2# Ordinary | 1# Green | 2# Green |
|------------------------|-------------|-------------|----------|----------|
| Optimal water content (%)| 4.7         | 4.5         | 4.8      | 4.7      |
| Maximum dry density (g/cm³) | 2.25        | 2.21        | 2.37     | 2.32     |
Table 4 indicated the same trend: the use of green cement can significantly increase the maximum dry density of inorganic binding material, mainly because green cement could fill the natural graded gravel compactly, and green cement could react well with fine soil particles, and increase the overall compactness of natural graded gravel, reduce the impact of water damage, and improve the durability of natural graded gravel of cement stabilized base. The fineness of green cement is greater than that of ordinary Portland cement, and the optimal water content is not varied significantly, mainly because the green cement contains high-efficiency superplasticizer as an additive.

### 4.3. Compressive strength test

![Compressive Strength](image1.png)  
![Standard deviation](image2.png)  
![Coefficient of variation](image3.png)

- a) Compressive Strength.  
- b) Standard deviation.  
- c) Coefficient of variation.

**Figure 2.** The comparison of a) compressive strength, b) standard deviation and coefficient of variation

As can be seen from Figure 2, the compressive strength of both specimens have been significantly improved by using green cement. In the compressive strength test, 15 specimens were tested each group, the standard deviation of green cement bonded specimens is significantly lower than that of ordinary Portland cement. It is proved that the effective strength of green cement bonded base is more stable than that of ordinary Portland cement, and the coefficient of variation of compressive strength by using green cement is much smaller than the specification value, which indicated that the bonding of green cement is strong enough to bind fine soil particles in the natural graded gravel structure, and make up for the defect of the larger soil content of natural graded gravel.
4.4. **Splitting strength test**

![Figure 3. Splitting strength comparison of cement stabilized base specimens with 2 type of binders.](image)

In order to explore the anti-pull resistance of the natural grade gravel of green cement curing, the splitting strength test was carried out. As shown in Figure 3, the splitting strength increased with curing period increasing, the splitting strength of 28d of 1# is 0.32 Mpa, and the splitting strength of 28d of the 2# material is 0.36 Mpa when using green cement. The splitting strength of specimens made with green cement is significantly higher than that of ordinary silicate cement, mainly because the green cement can form a three-dimensional spatial mesh slurry, which could wrap the soil particle surface well, then enhance the strength of the bonding transition zone between the aggregates, and improve the overall strength of the specimens.

4.5. **Resilient modulus test**

![Figure 4. Resilient modulus](image)

As can be seen from the Figure 4, the resilient modulus increased with the growth of the aging period. The resilient module of 28d of specimens made of green cement is 3155 Mpa and 3544 Mpa respectively, and has reached the highest value of the various cement stabilized base materials resilient modulus (3000-4200 Mpa) given in JTG D50-2006 Road Asphalt Pavement Design Specifications. It is shown that the natural graded gravel with green cement adding has good stiffness and meets the requirements of the use of the road base material.
5. Conclusion
Natural graded gravel has good performance on forming cement stabilized base when using green cement as the binder, which could replace manual graded natural stone. Shows an energy-saving and environmental-friendly way of raw materials for road construction.

Green cement gel could solidified natural graded gravel compactly, shows higher compressive strength, splitting strength and resilient modulus than that of ordinary Portland cement.

Both kinds of aggregates are wide-ranged distributed materials from local construction site. Green cement can make up for the defects that traditional cement could not deal with wide-ranged raw material and high soil content well. This kind of material has a broad application prospect in road construction field.

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