Experimental Study on Rapid Solidification of Sand with Cement Emulsified Asphalt Perfusion Material

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Abstract. This paper closely combined the requirements of emergency rescue and reinforcement of hydraulic engineering, developed cement emulsified asphalt quick hardening perfusion materials with yellow sand and clay locally, and conducted solidification test on rockfill. The results show that, when the mass percentage of emulsified asphalt is 0~50%, the 3d compressive strength of the yellow sand perfusion solidified body can reach 15.6~33.3MPa, the clay perfusion solidified body can reach 2.2~3.1MPa, and the compressive strength decreases linearly with the increase of emulsified asphalt content, and the tensile-compression ratio increases with the increase of the emulsified asphalt content. The permeability coefficient is on the order of 1×10⁻⁸~1×10⁻⁹m/s. It can be seen that the cement emulsified asphalt infusion solidified body has high early strength, good crack resistance and toughness, and can meet the requirements of rapid curing, and is suitable for engineering with high requirements on the deformation performance of the solidified body.

1. Introduction
To meet the requirements of emergency rescue and reinforcement of water conservancy projects, yellow sand and clay are used respectively to develop cement emulsified asphalt perfusion material to cement loose earth and stone into hard blocks quickly. The cemented earth-rock body has the characteristics of strong deformation adaptability, no formation washed by water, anti-scouring and anti-foaming.

2. Experimental materials
Cationic emulsified asphalt with penetration of 7.23 mm, softening point of 46.2 °C, ductility of more than 100 cm at 15 °C and solid content of 60.0% is used in the test. The cement used is R.SAC42.5 grade sulphaaluminate cement with density of 2.87g/cm³, fineness of 0.32%, specific surface area of 490m²/kg, initial setting time of 13.5min and 28d strength of 60.5MPa. Additives are polycarboxylic acid superplasticizer, retarder and polyether defoamer. Yellow sand with fineness modulus of 1.73 and clay with low liquid limit are used as filling sand, and their grain size distributions are shown in Fig. 1 and Fig. 2 respectively. Yellow sand belongs to the fine sand in Area 3 of "Construction Sand"(GB/T 14684-2011).
3. Mix proportion and strength test of perfusion material

The size of the perfusion material specimens is 40 mm×40 mm×160 mm. They are formed by self-flow pouring and are placed in the curing room with temperature of 20°C±2°C and relative humidity of 60%±5%. After 3 days, remove the mould and maintain the specimens to the test age. The mix proportion and strength test results of yellow sand and clay perfusion materials are shown in Tab. 1, Fig. 3 and Fig. 4.

The test results show that under different emulsified asphalt content, the 3d,7d compressive strength of yellow sand perfusion material is 16.3~33.8MPa and 19.0~38.0MPa respectively, and that of clay perfusion material is 2.3~3.97MPa and 2.81~5.26MPa respectively. The compressive strength decreases linearly with the increase of emulsified asphalt content. The average compressive ratio of clay perfusion material is higher than that of yellow sand perfusion material. The compressive ratio basically increases with the increase of emulsified asphalt content, and it becomes the lowest without emulsified asphalt, which indicates that the toughness of the perfusion material can be improved by adding emulsified asphalt.

Table 1. Results of mix proportion and strength tests of perfusion material

| Number | Cement-sand ratio | Emulsified asphalt content (%) | Water-binder ratio | Water reducer content (%) | Retarder content (%) | Deoamer content (%) | Compressive strength (MPa) | Flexural strength (MPa) | Average compressive ratio |
|--------|------------------|-------------------------------|--------------------|---------------------------|--------------------|---------------------|--------------------------|-------------------------|--------------------------|
| yellow sand-0 | 1:1.5 | 0 | 0.49 | 0.30 | 0.25 | 0.05 | 33.8 | 38.0 | 43.2 | 4.37 | 3.86 | 4.46 | 0.11 |
| yellow sand-20 | 1:1.5 | 20 | 0.49 | 0.30 | 0.35 | 0.05 | 25.6 | 30.3 | 36.9 | 4.23 | 3.52 | 5.08 | 0.14 |
| yellow sand-30 | 1:1.5 | 30 | 0.49 | 0.30 | 0.35 | 0.05 | 21.7 | 27.5 | 31.8 | 4.27 | 4.07 | 4.61 | 0.16 |
| yellow sand-40 | 1:1.5 | 40 | 0.49 | 0.30 | 0.35 | 0.05 | 20.2 | 22.2 | 26.2 | 4.48 | 3.3 | 4.58 | 0.18 |
| yellow sand-50 | 1:1.5 | 50 | 0.49 | 0.30 | 0.35 | 0.05 | 16.3 | 19.0 | 20.7 | 3.42 | 2.77 | 4.1 | 0.18 |
| clay-0 | 1:2 | 0 | 1.47 | 0.30 | 0.30 | 0.05 | 3.97 | 5.26 | 6.09 | 1.22 | 1.2 | 1.75 | 0.27 |
| clay-20 | 1:2 | 20 | 1.48 | 0.30 | 0.30 | 0.05 | 3.10 | 4.56 | 5.38 | 1.02 | 1.1 | 1.99 | 0.31 |
| clay-30 | 1:2 | 30 | 1.48 | 0.30 | 0.30 | 0.05 | 3.06 | 4.35 | 4.92 | 1.1 | 1.3 | 1.9 | 0.35 |
| clay-40 | 1:2 | 40 | 1.48 | 0.30 | 0.25 | 0.05 | 2.38 | 3.38 | 4.78 | 0.9 | 1.06 | 1.59 | 0.34 |
| clay-50 | 1:2 | 50 | 1.48 | 0.30 | 0.30 | 0.05 | 2.36 | 2.81 | 4.68 | 0.8 | 0.74 | 1.39 | 0.30 |

Note: 1) The content of emulsified asphalt and admixture is the percentage of cement quality.
2) The controlled fluidity is more than 300 mm and the hardening time is 0.5~1.0h.
4. Rockfill filling test

4.1. Strength test

The specimen size of rockfill filling test is 100mm×100mm×100mm. The strength filling test is carried out with the above-mentioned perfusion material. The limestone artificial aggregate and natural river pebble aggregate with 12.5~31.5mm are loosely loaded in the test models. The yellow sand and clay perfusion materials are respectively used for filling, self-leveling and self-compacting, and the maintenance conditions are the same as above. The specimens mixed with emulsified asphalt do not break after splitting. The strength test results of the filling solidified body can be seen in Tab. 2, Fig. 5 and Fig.6.

**Tab. 2 Strength test results of solidified body**

| Number       | Emulsified asphalt content (%) | Compressive strength (MPa) | The strength growth rate (%) | Splitting tensile strength (MPa) | Average tension-compression ratio |
|--------------|--------------------------------|---------------------------|----------------------------|---------------------------------|---------------------------------|
| yellow sand-0| 0                              | 33.3 46.4 48.4            | 69 96 100                   | 2.62 2.58 2.19                  | 0.060                           |
| yellow sand-20| 20                             | 22.3 28.0 28.6            | 78 98 100                   | 1.98 1.90 1.91                  | 0.074                           |
| yellow sand-30| 30                             | 20.5 24.4 24.7            | 83 99 100                   | 1.92 1.88 -                     | 0.079                           |
| yellow sand-40| 40                             | 16.5 19.5 23.9            | 69 82 100                   | 1.76 1.81 1.93                  | 0.093                           |
| yellow sand-50| 50                             | 15.6 16.4 16.6            | 94 99 100                   | 1.53 1.75 1.92                  | 0.107                           |
| clay-0       | 0                              | 3.10 4.68 5.19            | 60 90 100                   | 0.36 0.49 0.51                  | 0.12                            |
| clay-20      | 20                             | 2.67 3.38 4.30            | 62 83 100                   | 0.38 0.43 0.46                  | 0.12                            |
| clay-30      | 30                             | 2.35 3.11 4.05            | 58 77 100                   | 0.42 0.43 0.56                  | 0.15                            |
| clay-40      | 40                             | 2.25 2.84 3.79            | 59 75 100                   | 0.36 0.36 0.50                  | 0.14                            |
| clay-50      | 50                             | 2.20 2.75 3.67            | 60 75 100                   | 0.32 0.31 0.45                  | 0.13                            |

Figure 3. Results of compressive strength tests of yellow sand perfusion material.

Figure 4. Results of compressive strength tests of clay perfusion material.

Figure 5. Compressive strength test results of the yellow sand filling solidified body.

Figure 6. Compressive strength test results of the clay filling solidified body.
The results show that the 3d, 7d compressive strength of the yellow sand filling solidified body is 15.6 ~33.3MPa and 16.4~46.4MPa respectively, and that of clay filling solidified body is 2.2~3.1MPa and 2.8~4.7MPa respectively. The compressive strength decreases linearly with the increase of emulsified asphalt content, and the early strength of the solidified body is higher, which can meet the requirements of rapid solidification of rockfill. The average growth rate of 3d and 7d strength of yellow sand solidified body is 79% and 95%, respectively. The strength growth rate of early age is fast, but slows down after 7 days. The average growth rate of 3d and 7d strength of yellow sand solidified body is 60% and 80% respectively. The average tension-compression ratio of clay solidified body is higher than that of yellow sand solidified body. The tension-compression ratio increases with the increase of emulsified asphalt content, and is the lowest when no emulsified asphalt is added, which shows that the crack resistance of the solidified body can be improved by adding emulsified asphalt into the perfusion material.

4.2. Elastic modulus test
In the elastic modulus filling test, the cylindrical specimens with a diameter of 100 mm and a height of 200 mm are used. Limestone artificial aggregate with a diameter of 12.5 – 31.5 mm and natural river pebble aggregate are loosely loaded in the test model. Yellow sand and clay perfusion materials are respectively used for filling, self-leveling and self-compacting, and the maintenance conditions are the same as above. The results of elastic modulus test of filling solidified body are shown in Fig.7 and Fig.8.

The test results show that the axial compression elastic modulus and axial compressive strength of yellow sand solidified body at the age of 7d are 21.9~33.9GPa and 10.4~27.4MPa, respectively. And that of clay solidified body at the age of 28d are 1.01~5.76GPa and 1.18~6.01MPa, respectively. The axial compression elastic modulus and axial compressive strength decrease linearly with the increase of the content of emulsified asphalt. The stress-strain curve of yellow sand solidified body with the emulsified asphalt content of 30% at the age of 7d is shown in Fig. 9. The damage morphology of the elastic modulus samples of yellow sand solidified body with different emulsified asphalt content is shown in Fig. 10. It can be seen that the specimens without emulsified asphalt are damaged obviously, and the higher the content of emulsified asphalt, the more intact the specimens become.

4.3. Impermeability test
The impermeability test is carried out with mortar impermeability tester. The upper diameter of the test mould is 70mm, the lower diameter is 80mm, and the height is 30 mm. The artificial aggregate of limestone with the diameter of 10~12.5mm is loosely packed in the mould. The yellow sand and clay perfusion materials are respectively used for perfusion, and are self-leveling and self-compacting. The water pressure starts at 0.1MPa and keeps constant after pressure to permeability. The permeability coefficient is calculated according to Darcy's formula. The results of impermeability test are shown in Tab. 3. The permeability coefficients of yellow sand solidified body are $1.09 \times 10^{-9}$~$2.71 \times 10^{-9}$m/s, and that of clay solidified body is $5.50 \times 10^{-8}$m/s. So, the former is one order of magnitude smaller than the latter. Adding emulsified asphalt has little effect on the permeability coefficient of solidified body.
Figure 7. Results of the elastic modulus and axial compressive strength tests of the yellow sand filling solidified body (7d).

Figure 8. Results of the elastic modulus and axial compressive strength tests of the clay filling solidified body (28d).

Figure 9. The stress-strain curve of yellow sand solidified body (the emulsified asphalt content of 30%, 7d).
Figure 10. The damage morphology of the elastic modulus samples of yellow sand solidified body.

Tab.3 Results of impermeability tests (28d)

| Number       | perfusion material mix ratio | Cement-sand ratio | emulsified asphalt content (%) | Water-binder ratio | Water reducer content (%) | Retarder content (%) | Defoamer content (%) | Permeability coefficient (m/s) | Seepage pressure (MPa) |
|--------------|------------------------------|-------------------|-------------------------------|-------------------|--------------------------|---------------------|------------------------|-------------------------------|-----------------------|
| yellow sand-0 |                              | 1:1.5             | 0                             | 0.65              | 0.3                      | 0.3                 | 0.05                   | 1.82×10⁻⁹                     | 0.28                   |
| yellow sand-30|                              | 1:1.5             | 30                            | 0.7               | 0.3                      | 0.3                 | 0.05                   | 2.71×10⁻⁹                     | 0.28                   |
| yellow sand-50|                              | 1:1.5             | 50                            | 0.65              | 0.3                      | 0.3                 | 0.05                   | 1.09×10⁻⁹                     | 0.28                   |
| clay-30       |                              | 1:2.0             | 30                            | 1.48              | 0.3                      | 0.3                 | 0.05                   | 5.50×10⁻⁸                     | 0.08                   |

5. conclusion
With emulsified asphalt content of 0-50%, the 3d compressive strength of yellow sand filling solidified body can reach 15.6~33.3MPa, and that of clay filling solidified body can reach 2.2~3.1MPa. The compressive strength decreases linearly with the increase of emulsified asphalt content, the tension-compressive ratio increases with the increase of emulsified asphalt content, and the magnitude of the permeability coefficient is about 1×10⁻⁸~1×10⁻⁹ m/s. It can be seen that the cement emulsified asphalt filling solidified body has high early strength, good crack resistance and toughness, which can meet the needs of rapid solidification, and is suitable for engineering with high deformation performance of the solidified body.

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