Experiment on Semi-Flexible Pavement Materials with Gold Tailings Cemented Mortar

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Abstract. Gold tailings (GT) are fine particles expelled after extraction of target metals and minerals from gold ore. The particle sizes mainly concentrate between 0.045mm and 0.15mm, and with richer metallic components and fewer sulfides. GT are largely underused in building materials. Considering engineering properties of grouted semi-flexible pavements (SFP) and the special characteristics of GT, such as its fine particle size and higher content of metals and sulfides, an experiment on SFP grouted with gold tailings cemented mortar (GTCM) is conducted. In cement mortar, the whole natural sand is substituted by GT. Referring to local standard DB11/T 1817, experiment on technical parameters of GTCM, base asphalt mixture, and SFP material grouted with GTCM are carried out. The results show that: when the mass of GT accounts for 28% of the cement mortar, the water-to-solid ratio is 0.69, and the dosage of polycarboxylate powder super plasticizer is 0.05%, GTCM with a flowability value of 9s to 11s, a 7d compressive strength of 15.8MPa, a 7d flexural strength of 3.8MPa, and no detected drying shrinkage can be prepared. The base asphalt mixture is designed with an interconnected porosity rate (IPR) 24.5%. At the flowability value 9s-11s, the perfusion ration(PR) of SFP specimens grouted with GTCM is 92.2%, with a 7d dynamic stability value 20020 times/mm, a 7d stability value 20.85KN. The study verifies that GT can wholly substitute natural sand used in grouted cement mortar.

Keywords: semi-flexible pavement; gold tailings; cemented mortars; interconnected porosity rate; perfusion ration

1 Introduction

Compared to conventional asphalt concrete pavements, SFP can significantly enhance load-carrying capacity and high-temperature stability by utilizing combined force from interlocking action between coarse aggregates in asphalt mixture and hardened strength

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of grouted cement mortar (GCM). Now SFP is typically used as an anti-rutting structural layer on road surface[1-2]. The strength of SFP materials is mainly influenced by the strength of GCM, with a ratio being about 11% of GCM strength[3]. However, low-temperature crack resistance of SFP materials is reduced compared to conventional asphalt mixtures, and drying shrinkage resistance of GCM is directly related to crack resistance of SFP[4-6]. The uneven increase in strength during setting process of GCM leads to drying shrinkage of cement paste, and when shrinkage stress exceeds interfacial bonding strength between cement paste and asphalt, cracks occur at the interface.

To reduce interface cracking between cement paste and asphalt, a large number of studies on SFP with GCM have emerged. Research related to grouting materials of SFP can be summarized into four categories: cement mortar mix ratio research[7-10], cement mortar chemical modification research[11-15], chemical-mechanical integrated modification research[16-19], and new cementitious material mortar research[20-24]. In the first category, the main materials of cement mortar are ordinary cement and natural sand. The research mainly revolves technical parameters such as water-cement ratio, water-binder ratio, and sand-binder ratio, exploring the rules in compressive and flexural strength, drying shrinkage deformation, and flowability of cement mortar changing with the aforementioned parameters. In the second category, common modification method is to add some modifier into cement mortar, such as polymer emulsions, resins, polymer emulsions, rubber powder, and emulsified asphalt, etc. By comparing the modified cement paste with conventional cement mortar, cement mortar with improved physical and mechanical properties is obtained, and then enhancing low-temperature cracking resistance. The third category of research involves adding expansive agents to cement mortar, causing cement paste to expand during setting and hardening process, compensating for drying shrinkage of cement paste. The performance of expansive cement mortar is influenced by various factors, including type of cement, dosage of expansive agent, type and particle size of fine aggregate, water dosage, stirring and curing conditions, etc. The dosage of expansive agents has a significant impact on expansion degree of cement paste, and an excessive amount can decrease strength of cement paste. The mix design of expansive mortar for SFP is crucial and needs to consider many factors such as application scope, load characteristics, and climate, etc. The fourth category integrates recycling of industrial solid waste and developing new building materials, using geopolymer cementitious materials to partially or completely replace cement for preparation of grouting materials, aiming to dispose of solid waste and reduce engineering costs.

GT are ultra-fine particulates expelled after extraction of target metals and minerals from gold ore, with particle sizes mainly concentrated between 0.045mm and 0.15mm. GT contains relatively richer metallic components, fewer sulfides and sometimes very fewer cyanide, which result to a much smaller recycling utilization of GT. Combining GT's material characteristics and SFP's engineering characteristics, GTCM SFP is designed to realizing recycling of GT and developing new construction materials in this study. The current engineering applications of SFP is relatively mature. Based on existing research, GT is utilized to substitute for fine sand in cement grouting in this study, and experiments are conducted on GTCM SFP.

2 Methodology

This study primarily refers to the local standard DB11/T 1817 and is conducted through experimental methods. The entire research process includes three parts of experiments: First, it verifies the feasibility of using gold tailings as a substitute for natural sand in semi-flexible pavement cement grouting, including testing mix ratio, strength, fluidity, and other indicators of gold tailings cement slurry through experimental testing; then, it designs experiments for mix ratio and IPR of base asphalt mixture; finally, it tests PR of GTCM and dynamic stability of SFP infused with gold tailings cement slurry. Ultimately all the experiment results verify that gold tailings can fully replace natural sand in semi-flexible pavement cement grouting material.

3 Raw Material Technical Parameters

SBS modified SMA asphalt, P.O.52.5 cement and limestone are used in this study, and polycarboxylate-based cement concrete super plasticizer is adopted. The technical indicators of all raw materials meet the specified requirements of the relevant road engineering specifications. GT materials are obtained from Xincheng Gold Mine in Yantai City, Shandong Province, China, as shown in Fig. 1.

Fig. 1. Gold tailings

Table 1 presents sieving particle sizes of GT. The passing percentage of particles through a 0.075mm sieve is approximately 60%, and 80% of the particles concentrate in the range of 0.045mm to 0.15mm, which can be considered as superfine sand.

Table 1. GT particle size

Seive size (mm)	Mass (g)	Fractional residue (%)	Cumulative residue (%)	Passing (%)
0.3	0	0	0	100
0.15	70.70	14.14	14.14	85.86
0.075	129.59	25.92	40.06	59.94
0.045	273.52	54.70	94.76	5.24
<0.045	26.19	5.24	100.00	0
∑	500	100		

Table 2 presents chemical composition of GT. The key components content, such as SiO_2, Al_2O_3, Fe_2O_3 and SO_3 are separately 65.30%, 12.14%, 4.34% and 7.28%. Amorphous SiO_2 and Al_2O_3 make important roles in determining hydration activity of GT. A higher content of Fe_2O_3 can enhance flexural strength of gold tailings cemented materials, and a higher content of SO_3 can lead to expansion which can compensate for drying shrinkage cracks of GTCM in the later stages of strength formation.

Table 2. GT chemical components

Oxidates	SiO_2	Al_2O_3	SO_3	Fe_2O_3	K_2O	CaO	Na_2O	MgO	TiO_2
Content(%)	65.30	12.41	7.28	4.34	3.83	3.31	1.83	0.67	0.40

Industrial solid waste used in construction materials must comply with requirements ruled in standards GB5085.3-2007, HJ702-2014, and HJ484-2009. Table 3 shows the results of harmful substances contents which are lower than the specified limits, and then GT required from Xincheng Gold Mine can directly be used as raw materials of construction engineering without extra treatment.

Table 3. Hazardous substances in gold tailings

hazardous substances(μg /L)								Cyanide (mg/L)
Cu	Ar	Cd	Zn	Pb	Ni	Cr	Hg	
80	0.1	30	50	300	142	4	0.02	0.004

4 Base Asphalt Mixture Design

4.1 SFP-20 Asphalt Mixture Design

Referencing DB11/T 1817, aggregate mix ratio is selected within SFAC-20 gradation range, and gradation curve is calculated using rectangular diagram method, as shown in Fig. 2. Aggregates design curve is S-shaped, with finer coarse aggregate and coarser fine aggregate. Asphalt-to-aggregate ratio is preliminarily set at 2.7%, 2.9%, and 3.1%. The amount of excessive free asphalt exuded at high temperatures from asphalt binder is determined based to Schellenberg extraction test method, with results of 0.25%, 0.28%, and 0.31% respectively. It can be seen that asphalt mixture with an asphalt-to-aggregate ratio of 3.1% has a relatively larger asphalt exudation. The Kentabro Fly-off test method is used to evaluate the smallest asphalt content in asphalt mixture, because insufficient binder can lead to loss of surface aggregate due to inadequate adhesion. The measured loss values corresponding to asphalt-to-aggregate ratios of 2.7%, 2.9%, and 3.1% are 20%, 18.8%, and 18.0% respectively. Considering both blockage of interconnected porosity by excessive asphalt and reduction in base mixture strength due to insufficient asphalt content, this study adopts an asphalt-to-aggregate ratio of 2.9%.

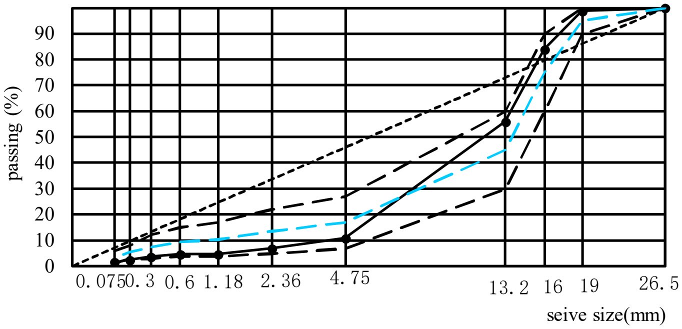

Fig. 2. SFAC-20 grade scope S-shaped gradation curve

4.2 IPR Design of Base Asphalt Mixture

IPR of base asphalt mixture specimen is tested using the device shown in Fig. 3. This communicating vessel consists of a cylindrical container with a diameter D_1 and a fine graduated glass tube with a diameter D_2. Asphalt mixture specimen is placed inside cylindrical container, and water level height can be accurately read from graduations on fine glass tube. The graduations on glass tube are required to be accurate to 0.1mm.Presumed that the diameter D_1 of cylinder is 15cm, and the reading accuracy for volume change caused by rise and fall of water level height is approximately 1.8ml, which meets testing requirements for IPR.

Calculating IPR by formula(1)~(3) , the volume V_1 of solid part and closed porosity part of specimen is the sum of increased water volume in these two tubes .

$$V_1 = \frac{\pi (D_1^2 + D_2^2) \times (h_2 - h_1)}{4} \tag{1}$$

Finally, IPR can be calculated by formulae (2) and (3).

$$IPR = \frac{V - V_1}{V} \times 100\% \tag{2}$$

Among it ,

$$V = \frac{\pi D^2}{4} \times H \tag{3}$$

D——diameter of Marshall specimens(mm);
H——height of Marshall specimens(mm).

The equipment is simple and easy to operate, reducing errors in test process. It is very convenient to calculate V_1 and determine IPR based on the volume V of asphalt mixture specimen. Following the aforementioned method, IPR average of the specimens with an asphalt-to-aggregate ratio of 2.9% is 24.5%.

Fig. 3. IPR test equipment

5 GTCM Mix Design

In this study, three different sand-to-cement ratios (SCR) of 4:6, 3:7, and 2:8 are selected for preparation of gold tailings cement grout. When SCR was 4:6, the flowability could not easily reach 9s -10s. When SCR is 3:7 or 2:8, both the 7d compressive strength and flexural strength of GTCM meet the specified requirements, and the flowability value could also be adjusted to 9s-10s easily. Considering bulk utilization of industrial solid waste, the SCR ratio of GTCM ultimately is designed as 3:7, a water-to-cement ratio of 0.69, a dosage of polycarboxylate powder super plasticiser of 0.024%, and the 7d compressive and flexural strength of GTCM are 15.8 MPa and 3.8 MPa respectively.

6 GTCM Semi-Flexible Pavement Technical Performance

6.1 Perfusion Rate

The Marshall specimens filled with cement grout are sealed with plastic film and displaced at room temperature for 2 to 3 days. And then, specimens are remove into the apparatus shown in Fig.3 to measure the volume of water displaced. The residual IPR is calculated by formula (1) ~ (3), and the PR is calculated by formula (4):

$$PR = \frac{IPR_0 - IPR_1}{IPR_0} \times 100\% \tag{4}$$

Among them, IPR_0 represents the IPR of 24.5% before the cement grout is perfused, and IPR_1 represents the residual IPR of 1.9% after the cement grout is perfused. The PR is 92.2% which satisfies the requirements of specification DB11/T 1817.

6.2 Anti-Rutting Resistance

Fig. 4. Perfusing cement grout

Fig. 5. Rutting specimen

Following the same asphalt mixture design, rutting specimens are prepared, which are compacted by 8~12 rolls. After rutting specimens are cooled to room temperature, specimens assembled in the mold are perfused with the prepared GTCM, shown as Fig. 4. The mortar flowability value should be controlled within 9s to 10s.

The rutting specimens filled with cement mortar are sealed with a plastic bag, and dynamic stability test are performed after specimens are displaced at room temperature for 7 days. The test results are shown in Table 4. The average dynamic stability value of grouted semi-flexible pavement material is 20020 times/mm, and the average dynamic stability value of AC-20 asphalt mixture specimen is 5070 times/mm. The average rutting resistance of semi-flexible pavement specimens is approximately 3.95 times that of the ordinary asphalt concrete specimens. Fig. 5 shows a tested rutting specimen, which has a shallower indentation comparing to the classic asphalt mixture tested rutting specimens.

Table 4. Dynamic stability test(times/mm)

Mixture type	Dynamic stability			Average
AC-20	5030	5129	5050	5070
GTCM semi-flexible pavement	20006	20102	19958	20022

6.3 Water Damage Resistance

It is known that water damage resistance of SFP is not as good as that of ordinary asphalt concrete pavement. In this study, the same SBS modified asphalt and limestone aggregates are used to prepare specimens of AC-20 ordinary asphalt concrete as a comparison with SFP material. Both SFP specimens and AC-20 asphalt mixture specimens are placed at room temperature for 7 days, then Marshall stability and water immersion Marshall stability tests are conducted. The results are shown in Table 5. The residual stability of GTCM SFP after water immersion is 95.9%, better than the residual stability of ordinary asphalt mixture specimens at 90.2%.

Table 5. Residual stability test(KN)

Specimen		1	2	3	Average
GTCM SFP	Marshall stability	20.28	20.93	21.35	20.85
	Water immersion Marshall stability	19.35	19.41	19.73	19.50
	Residual stability(%)	93.49			
AC-20	Marshall stability	12.78	13.12	13.25	13.05
	Water immersion Marshall stability	11.58	12.52	11.22	11.77
	Residual stability(%)	90.20			

6.4 Freeze-Thaw Splitting Test

In order to evaluate freeze-thaw resistance and post-freeze-thaw water damage resistance of asphalt mixture, Marshall specimens of SFP material are conducted splitting test after frozen in -18°C condition for 16 hours, then keeping in 60°C water for 24 hours, and in 25°C water for 2 hours. The tested splitting strength values are shown in Table 6. The average splitting strength of unfrozen SFP asphalt mixture specimens was 1.04 MPa, and the average splitting strength after freeze-thaw was 0.98 MPa. The strength ratio of these two is 94.23%, which indicates that this SFP material with GTCM has good freeze-thaw resistance and water damage resistance.

Table 6. Freeze-thaw splitting strength(MPa)

Specimen	1	2	3	Average
Splitting strength	1.07	1.04	1.02	1.04
Freeze-thaw splitting strength	1.01	0.97	0.95	0.98
Freeze-thaw splitting strength ratio(%)	94.23			

7 Conclusions

(1) Experimental results have verified that GT can replace natural sand in preparation of GTCM material for SFP. The SFP material with GTCM meets all the technology requirements of specification DB11/T 1817.

(2) The 7d flexural and compressive strength of GTCM are better than those of ordinary cement mortar made of natural sand. The higher 7-day compressive strength may be related to the higher content of components such as Al_2O_3, K_2O, CaO, Na_2O in GT, which can promote early hardening speed of cement slurry. The higher 7d flexural strength is preliminarily judged to be related to the formation of $4CaO.Al_2O_3.Fe_2O_3$ due to high content of Fe_2O_3.

(3) The drying shrinkage deformation of GTCM is very small and undetectable, which should be related to the 7.28% content of SO_3. SO_3 reacts with CaO and Al_2O_3

in cement to form $Ca_4Al_6SO_{16}$ which plays a key role in compensating for drying shrinkage deformation during hardening process of cement grout.

(4) The flowability of GTCM can be easily adjusted to 9-10s, which is highly related to its particle fineness. The particle size of GT is concentrated between 0.045-1.15mm, which is enough fine and more evener than those fine parts sieving from natural sand.

The suggestion is field test roads will be used to further verify road performance of GTCM semi-flexible pavement.

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