Construction and Building Materials 170 (2018) 153–166

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Influence of coarse fly ash on the performance of foam concrete and its application in high-speed railway roadbeds

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HIGHLIGHTS

- Foam concrete was used to reduce the differential deformation of the railway track.
- Coarse fly ash enhances workability, mechanical and freeze-thaw resistance properties of foam concrete.
- Field testing shows good adaptability when foam concrete was used as a filling material.

ARTICLE INFO

Article history:
Received 11 November 2017
Received in revised form 22 February 2018
Accepted 28 February 2018

Keywords:
Foam concrete
Coarse fly ash
Durability
X-CT
Water transfer
High-speed railway roadbed

ABSTRACT

In this paper, the potential of using foam concrete as a lightweight filling material for high-speed railway roadbeds was studied. The influence of coarse fly ash on the workability, mechanical, shrinkage performances and durability of foam concrete were analyzed. X-ray Computed Tomography (XCT) was used to characterize the microstructure and quantitatively in situ monitor the water transfer behavior of foam concrete. The results show that coarse fly ash enhances many properties of foam concrete, including workability and mechanical and freeze-thaw resistance properties, while the reverse phenomenon is observed for water absorption and drying shrinkage properties. A good linear relationship was provided between the fine content and the absorption coefficients. Finally, continuous field testing of settlement, lateral displacement and soil pressure in the Hangzhou east railway station project shows good loading and differential settlement reduction properties when foam concrete was used as a filling material.

1. Introduction

China has been undergoing a high-speed railway building boom over the past decade. By the end of 2016, China had the world's longest high-speed rail network, with over 20,000 km of track in operation, which accounts for more than 60% of the high-speed railway distance in the world, and a total distance of 36,000 km has been planned before 2020 [1]. Not only are the new railway projects progressing steadily, but also multiple track railway projects have been launched on some busy lines. Therefore, the methods of preventing and reducing the differential deformation of the operating railway lines due to lateral soil pressure caused by the later railway line construction are very important considering the extremely strict requirements of smoothness and stability [2].

The existing measures for controlling different settlement of subgrade are based on the traditional treatment methods, which maintain the stability of subgrade by increasing the strength of foundation soil itself or adding extra high-strength support body. However, there is a higher probability of settlement when using traditional methods in some special areas, which is due to the insufficient bearing capacity or stiffness of the foundation, that is, the upper load exceeds the bearing capacity of the foundation [3]. Utilizing lightweight materials as a replacement filler is a good choice to reduce the loading pressure of the foundation, as shown in Fig. 1. Among the lightweight materials, foam concrete can be designed to have arbitrary density within the range of 300–1650 kg/m^3, which is self-compacting and possesses light weight, appropriate compressive strength (0.5–10 MPa) and good thermal insulation properties, suitable for application for insulation and filling projects [4–6]. Compared with other lightweight replacement material (Expanded Polystyrene block), foam concrete is economical and can be fabricated on the construction site [7,8]. It should be noted that the utilization of foam concrete is also expected to increase the anti-frost swelling property of

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https://doi.org/10.1016/j.conbuildmat.2018.02.207
0950-0618/

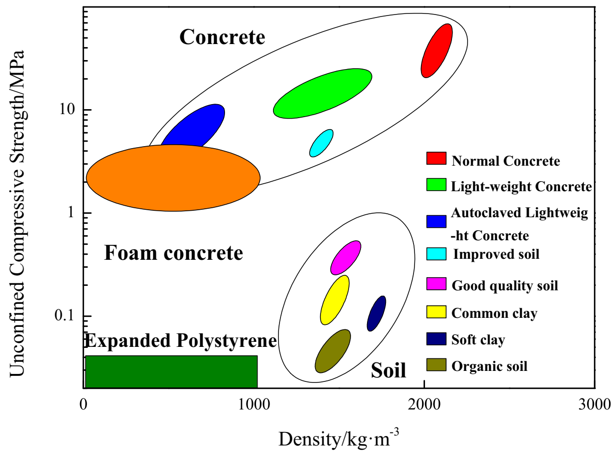

Fig. 1. Comparison of the properties between conventional packing materials and foam concrete [21].

high-speed roadbed in seasonally frozen areas because of its excellent thermal insulation property.

The existing studies mainly focus on mechanical and functional (thermal and energy absorption) properties of foam concrete [9–11]. The growing use of foam concrete for geotechnical fills raises the question of suitable durability and performance standards, which are important for practical application especially in high-speed railway foundation because of the harsh and changeable service environment (dynamic load, underground water) and strict deformation control standard [3].

Fly ash is a by-product of coal-burning power plants. It is widely used as a cementitious material and a pozzolanic mineral admixture in concrete. Many researchers [12–14] concluded that high fineness of classified fly ash was useful in increasing the mechanical properties of concrete. However, coarse fly ash contains a large part of crystalline phases, which should not be directly used in concrete because of its resulting low pozzolanic activity [15]. Although the utilization rate of fly ash increased year by year in China, which was about 70% in 2016, there were still 180 million tons of fly ash accumulated due to the large amount of coal used for thermal power plant. The large amount of coarse fly ash not only takes up valuable land resources, but also poses an indirect threat to the environment and human health [16]. For the absence of aggregate, the drying shrinkage and water absorption of foam concrete are higher than that of normal concrete [8]. The addition of fine fly ash can reduce the heat of hydration and decrease the drying shrinkage of foam concrete without dramatically changing its mechanical properties [17]. However, the influence of coarse fly ash on the performance of foam concrete is still less understood. Compared with normal concrete, foam concrete shows greater potential in high-capacity utilization of industrial wastes because strength is not a major concern considering its field of application [18–20]. Therefore, the study of the influence of coarse fly ash on the performance of foam concrete will not only hopefully improve some of the properties of foam concrete, but will also provide a means of economic and safe disposal of these waste residues.

The objective of this work is to investigate the influence of coarse fly ash (as a replacement for sand) on the consistency, strength, drying-shrinkage properties and durability (water transfer and freeze-thaw resistance) of foam concrete. XCT was also used to visually and quantitatively characterize the pore structure and water transfer behavior of foam concrete. Finally, the field tests of settlement, lateral displacement and soil pressure of the underground in the Hangzhou east railway station were conducted to study the long-term feasibility (3 years to date) of foam concrete filling roadbed.

2. Experimental work

2.1. Materials

The Portland cement (PC) was used in the foam concretes and was conformed to the ASTM Standard Specification [22]. The physical and chemical characteristics of PC are summarized in Table 1. Fine fly ash (FA_f) and Coarse fly ash (FA_c) both conformed to ASTM C 618 [23] were used and the median particle size is 21 μm and 98 μm respectively. Their physical and chemical characteristics are also summarized in Table 1. The corresponding size distribution of PC, FA_f, FA_c are shown in Fig. 2. Natural sand was used as a fine aggregate in foam concrete which is in medium grade, conforming to ASTM C 33 [24] with a fineness modulus of 2.31. The median particle size is 0. 4 mm. A protein foaming agent was used in the experiment and the dilution ratio was 1:20 by weight. Foam is produced in a foam generator with an apparent density of 50 kg/m^3.

2.2. Mix proportions

The mix proportions of foam concrete, which are summarized in Table 2, were calculated by equating the design plastic density value to the sum of solids and water in the mix which has been developed by the University of Dundee [8,25]. A previous study showed that a greater amount of cement in the mix results in more heat of hydration and thus, a higher risk of thermal cracking, so the amount of cementitious material is limited to 300 kg/m^3. However, when FA_c was introduced as the replacement of sand, the content of FA_c was considered in the w/b ratio to ensure there was enough free water available to 'wet' the large surface area of the particles. The w/b ratio (binders: cement, fine and coarse fly ash) and fine fly ash replacement ratios were retained at 0.50 and 30%, respectively. Nine mixtures were prepared to study the effect of the replacement ratio of coarse fly ash (0%, 50% and 100%) at three different densities (1000, 1200 and 1400 kg/m^3).

2.3. Specimen preparation

Foam concrete was produced by an integrated machine, which including foaming and mixing systems. The cementitious material and fine aggregates are first dry-mixed for 1 min. Then the water is added to the premixed powders and mixed for 3 min. Finally, the preformed foam generated by a compressed gas system is added and mixed for 3 min until the foam is uniformly distributed in the mix. The plastic density of the mix is then measured and values within ±50 kg/m^3 are accepted. If the density is higher than the design value, additional foam is added incrementally until the target value is achieved, followed by further mixing. If the density is lower, the mixes are rejected and repeated again. After being mixed, the foam concrete paste is cast into molds and then covered with cling film to prevent water evaporation. After 24 h, the specimens are unmolded and stored in a standard curing room (20 °C, 100% RH) until testing.

2.4. Testing methods

2.4.1. Consistency

The consistency of the foam concretes was characterized through the measurements of "spreadability" according to the Brewer test, which measured the spread in two directions of sample placed in a 75-mm diameter and 150 mm height cylinder after the cylinder was lifted up [26], and "flow time" according the Mod-