Effect of Air-entraining Agent and Mineral Admixture on Thixotropy Property of Fresh Concrete

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ABSTRACT: The elevation control of concrete bottom slab in curve line section of high-speed railway is difficult because fresh concrete cannot hold its shape and the slope of fresh concrete cannot maintain effectively before concrete hardened. To solve this problem, air-entraining agent and attapulgite clay mineral admixture were used to improve the thixotropy of fresh concrete. Results indicated when air-entraining agent and attapulgite clay incorporated simultaneously, the static yield stress of fresh concrete increased to 9.78 N·m, the dynamic yield stress decreased to 5.56 N·m, the ratio between the static and dynamic yield stress increased to 1.9, and the ability of holding the shape and slope was improved to 95.6%. This is mainly due to fibrous gel structure and orientation distribution of attapulgite clay and spherical air bubbles introduced by air-entraining agent in fresh slurry. These will provide valuable and useful references for quality and elevation control of concrete bottom slab of ballastless track in curve line section of ballastless track.

KEYWORDS: Concrete; Thixotropy; Rheology; Attapulgite clay; Air-entraining agent; Bottom slab.

1 INTRODUCTION
The concrete bottom slab is an important structural part and the main load-bearing element of ballastless track [1-4]. Engineering practice shows the ultra-high shape and elevation control of bottom slab in the curve line section of high-speed railway are difficult on site. To achieve the designed ultra-high elevation between both sides of concrete bottom slab, which can be up to 175 mm (shown in Figure 1), during the construction process, in addition to adjusting the corresponding height of steel molds on both sides of the bottom slab, shape the designed elevation for both sides of bottom slab after pouring and vibrating process is very important. However, under the action of gravity, the fresh concrete cannot hold the shape before concrete hardened, so construction workers need to scrape the fresh concrete for many times, causing a waste of manpower, and the results are still not satisfactory. The designed elevation of bottom slab and drainage slope is difficult to control accurately. On the one hand, inadequate drainage slope or reverse slope is not conducive to drainage for ballastless track.
In order to meet the need of pumping concrete easily, the slump of fresh concrete is generally much higher than 16 cm during the current concrete construction of bottom slab. Therefore, the fresh concrete still has high fluidity after vibrated, the concrete cannot hold the shape and the ultra-high elevation between both sides of bottom slab cannot maintain effectively. In order to solve this problem, a key for designing a concrete mixture to balance the flowability that is required for pumping and consolidating easily during dynamic processing (e.g.: pumping, pouring, vibration, etc.), and the thixotropy that is required for timely shape-holding in the static state (such as: after the slope scraped and finished). The well-designed concrete mixture shall possess unique rheological properties, including fluidity and shape stability. In this paper, we used the air-entraining agent and attapulgite clay mineral admixture to improve the thixotropic properties of fresh concrete and reach this balance. This research will provide a simple, effective and reliable technical measure for elevation control of bottom slab of ballastless track in curve line section on site [6-7].

2 EXPERIMENTAL MATERIALS

2.1 Materials

(1) Cement: 42.5 ordinary Portland cement (C) confirming to GB 175 was used; the specific surface area of 355 m²/kg, the initial setting of 81 min, the final setting of 159 min, the loss on ignition of 2.82%, the compressive strength of 28d was 53.9 MPa.

(2) Fine aggregate: Locally available natural sand with a specific gravity of 2.69 and fineness modulus of 2.9 was used, the clay content of 1.5%, the water absorption rate of 1.3%.

(3) Coarse aggregate: Locally available crushed stone with a maximal nominal size of 20 mm was used, the clay content of 0.1%, the flakiness particle content of 3.5%.

(4) Mineral admixtures: Level I fly ash production (FA) with specific surface area of 5400 cm²/g was used, the fineness of 8.7%, the water demand rate of 94%, the loss on ignition of 4.59%; Grinding attapulgite clay gel powder with microfiber needle morphology was used, the main chemical composition was (Mg,Al)₅Si₈O₂₀•4H₂O. The particle size distribution tested by the Malvern Mastersizer 2000 laser particle size analyzer. The d (0.5) average particle size was 7.161 μm.

(5) Superplasticizer: Polycarboxylate superplasticizer confirming to GB 8076 with 27% water reducing rate was used.

(6) Air-entraining agent: SJ-2 type saponin air-entraining agent consisting essentially of monosaccharide group, glycoside bond and a glycone group was used. It is a non-ionic surfactant containing both hydrophilic and hydrophobic genes and easily...
soluble in water with strong chemical stability in acid, alkali and hard water. The main performance of its water solution was shown in Table 1.

Table 1. The main performance of air-entraining agent water solution.

| Concentration (%) | Foam volume (ml) | Bubble volume after 5 min (ml) | Foam stability (%) | pH Value |
|-------------------|------------------|-------------------------------|--------------------|----------|
| 0.4               | 52               | 47                            | 90.4               | 6.89     |
| 0.65              | 61               | 55                            | 90.2               | 6.37     |
| 0.8               | 67               | 61                            | 91.0               | 6.01     |
| 1.3               | 73               | 69                            | 94.5               | 5.49     |

2.2 Concrete mix proportions

Three mixture proportions of concrete were given in Table 2. The water/binder ratio and sand rate for every mix was 0.4 and 40%, respectively. The concrete slump was 12 cm±1 cm by adjusting superplasticizer dosage. The mixing procedure adopted was as follows: First, the cement, fly ash, air-entraining agent and mineral admixtures were dry mixed till a uniform color was obtained without any clusters of binders to make attapulgite clay gel powder distributed uniformly. Weighed quantities of coarse aggregates and sand were then mixed in dry state, thoroughly until a homogeneous mix was obtained. The slump and air content of fresh concrete were also shown in Table 2.

Table 2. Three mixture proportions of concrete.

| No. | A    | B    | C    |
|-----|------|------|------|
|     | Cement | 304  | 304  | 304  |
|     | Fly Ash | 76   | 76   | 76   |
|     | Attapulgite Clay | 0    | 0    | 2.28 |
|     | Sand | 745  | 745  | 745  |
|     | Crushed Stone | 1120 | 1120 | 1120 |
|     | Water | 152  | 152  | 152  |
|     | Superplasticizer | 3.8  | 4.0  | 4.5  |
|     | Air-entraining agent | 0    | 0.15 | 0.15 |
|     | Slump/cm | 12   | 12   | 13   |
|     | Air Content/% | 2%   | 6%   | 6%   |

3 EXPERIMENTAL METHODS

3.1 Slump and air content

In accordance with “Standard for test method of mechanical properties on ordinary concrete” (GB/T50081-2002).

3.2 Yield stress of fresh concrete

Fresh concrete can be considered as a fluid, which means that it will flow under the action of shear stresses, and yield stress represents the shear stress required to initiate flow. Concrete, however, is not a simple fluid because it displays thixotropic behav-
ior, which means that the shear stress required to initiate flow is high when the concrete has been in an “at rest” condition, but a lower shear stress is need to maintain flow once it has begun. This type of behavior is summarized in the schematic plot shown in Figure 2, which shows the variation in shear stress with time for the case of a slowly applied shear strain. At the start, the shear stress increases gradually with time but there is not flow. When the stress reaches the static yield stress, the concrete begins to flow and the stress required to maintain flow is reduced to the dynamic yield stress. If the applied shear strain is removed and the concrete is allowed to rest, inter-particle forces create a weak framework that restores the static yield stress.

Combined with the purpose of this research, to balance the flowability that is required for pumping and consolidating easily during dynamic processing and the thixotropy that is required for timely shape-holding in the static state. The fresh concrete mixture of well-designed shall possess higher static yield stress and lower dynamic yield stress. Moreover, the ratio between static yield stress and dynamic yield stress should be higher. The yield stress of fresh concrete was tested by RHM-3000 ICAR Rheometer. It is composed of a container to hold the fresh concrete, a driver head that includes an electric motor and torque meter; a four-blade vane that is held by the chuck on the driver; a frame to attach the driver/vane assembly to the top of the container; and a laptop computer to operate the driver, record the torque during the test, and calculate the flow parameters. The container contains a series of vertical rods around the perimeter to prevent slipping of the concrete during the test. The vane has a diameter and height of 127 mm. The shearing speed is 0.025rps. The rheometer software identifies the peak torque. The maximum torque corresponds to the static yield stress and then reduces to the dynamic yield stress. A typical stress growth plot and test equipment were shown in Figure 3.

3.3 Shape-holding ability of fresh concrete
The designed maximum ultra-high of ballastless track is 175 mm, and the corresponding sinusoidal slope is about 12.5%. To simulate this slope, the 360 mm × 200 mm ×
150 mm wooden molds was put on the vibration table, a steel heel block with the height of 40 mm was put under one side of the wooden mold (corresponding sinusoidal slope of 12.5%). Fresh concrete was poured in to the wooden mold and vibrated and flattened. And then, the steel heel block was removed gently as shown in Figure 4. Under the action of the gravity, the slope of the fresh concrete in the wooden mold would change. A vernier caliper was used to measure this deformation (the distance between the surface of fresh concrete and the horizontal spacing of wooden mold) in every 3 cm interval after the slope stabilized. The slope retention curve was drawn and different proportions of concrete slope retention curve were contrasted to evaluate the shape-holding ability of fresh concrete.

Figure 4. Test equipment of shape-holding ability of fresh concrete.

4 RESULTS AND DISCUSSIONS

4.1 Yield stress of fresh concrete

As shown in Figure 5, the static and dynamic yield torque of Concrete A were 8.51 Nm and 5.71 Nm, the ratio of static / dynamic yield torque was 1.5; the static and dynamic yield torque of Concrete B with air-entraining agent added were 7.06 Nm and 4.88 Nm, the ratio of static / dynamic yield torque was 1.4; the static and dynamic yield torque of Concrete C with air-entraining agent and attapulgite clay mineral admixture added were 9.78 Nm and 5.56 Nm, the ratio of static / dynamic yield torque was 1.8. Compared with Concrete A, the static and dynamic yield torque of Concrete B with air-entraining agent were decreased. This is because the air content of fresh concrete was increased from 2% to 6% with air entraining added, the air-entraining agent introduced a lot of micro bubbles in cement slurry, and these bubbles acted as miniature spherical balls, not only increase the fluidity of the slurry to improve the workability of concrete, but also increase lubrication action between the slurry and the aggregates which is conductive to sliding and rolling among different particles in fresh concrete. Therefore, the static and dynamic yield stress of fresh concrete with air-entraining agent were reduced obviously in either static or dynamic state.[8-9]

As also shown in Figure 5, compared with Concrete A, the static yield torque of Concrete C with air-entraining agent and attapulgite clay mineral admixture added was increased by 15% while the dynamic yield torque of Concrete C was decreased by 2.5%. It indicated air-entraining agent and attapulgite clay mineral admixture added simulta-
neously could increase the static yield stress obviously but decrease the dynamic yield stress of fresh concrete slightly. And compared with Concrete B, the dynamic yield torque of Concrete C was increased by 12% and the static yield torque of Concrete C was increased by 28%, the ratio of static / dynamic yield torque was increase from 1.4 to 1.9. This is mainly related to the fibrous structure of attapulgite clay mineral admixture. In the static state, on one hand, fibrous attapulgite clay distributed intertwined forming messy grids to play the role of constraining the movement of cement slurry and aggregates in fresh concrete; on the other hand, fibrous attapulgite clay increased the surface roughness of slurry to limit the rolling or moving of aggregates, and thus the static yield stress of fresh concrete increased obviously. However, in the dynamic state, under the shearing action, the grid network formed by fibrous attapulgite clay was destroyed, and with the shearing displacement direction, fibrous attapulgite clay gradually distributed directionally, the constraining action of this mineral admixture to different particles in fresh concrete was weakened or eliminated. Moreover, due to the balling and lubrication action of micro bubbles introduced by air-entraining agent in fresh concrete, the fluidity of fresh concrete increased and the workability improved, and thus the dynamic yield stress of fresh concrete decreased significantly with air-entraining agent and attapulgite clay mineral admixture added simultaneously.

4.2 Shape-holding ability of fresh concrete

The test results of shape-holding ability of Concrete A, B and C were shown in Figure 6. The triangular slope including two straight lines represent initial shape of fresh concrete (sinusoidal gradient of 12.5%). In contrast to this initial slope, the slopes of all fresh concrete decreased. For Concrete B with air-entraining agent add, the slope between the lowest point and the highest point was only 7.5% with the slope-holding rate of 60.0%; For Concrete A, the slope between the lowest point and the highest point was 9.7% with the slope-holding rate of 77.8%; For Concrete C with attapulgite clay mineral admixture and air-entraining agent added simultaneously, the slope between the lowest point and the highest point was 11.9% with the slope-holding rate of 95.6%. This indicated the shape-holding ability of fresh concrete decreased with the air-entraining agent added, which further demonstrated the balling and lubrication action of micro bubbles introduced by air-entraining agent improved the fluidity and workability of fresh concrete. This would be good for concrete pumping construction but bad for shape-holding after concrete placed. The shape-holding ability of fresh concrete was improved significantly with attapulgite clay mineral admixture and air-entraining agent added simultaneously. This indicated attapulgite clay mineral admixture could counteract the adverse influence of air-entraining agent on shape-holding ability but also enhance the shape-holding ability of fresh concrete by forming a network structure in slurry of fresh concrete.

![Figure 6. Test results of shape-holding ability of fresh concrete.](Note: the two straight lines represent the initial slope of fresh concrete, namely 12.5%)
5 CONCLUSIONS

(1) With air-entraining agent added, the static and dynamic yield stress of fresh concrete were decreased and the shape-holding ability was reduced. This is because the air-entraining agent introduced a lot of micro bubbles in cement slurry, and these bubbles act as miniature spherical balls increasing the fluidity of the slurry and improving the workability of fresh concrete.

(2) With air-entraining agent and attapulgite clay mineral admixture added simultaneously, the static yield stress of fresh concrete was increased and the dynamic yield stress was decreased. Meanwhile, the shape-holding ability was improved significantly. This is mainly related to the fibrous structure of attapulgite clay mineral admixture. The attapulgite clay mineral admixture can counteract the adverse influence of air-entraining agent on shape-holding ability but also enhance the shape-holding ability of fresh concrete by forming an intertwined fibrous network structure in slurry of fresh concrete.

(3) The attapulgite clay mineral admixture and air-entraining agent added simultaneously had no obviously adverse effect on workability performance of fresh concrete but improve the shape-holding ability with the slope holding rate up to 95.6%. This research will provide valuable and useful references for accurate elevation control of concrete bottom slab of ballastless track in curve line section of ballastless track.

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