Journal of King Saud University – Engineering Sciences 29 (2017) 381–387

Contents lists available at ScienceDirect

Journal of King Saud University – Engineering Sciences

journal homepage: www.sciencedirect.com

Original Article

Concrete mixtures with high-workability for ballastless slab tracks

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ARTICLE INFO

Article history:
Received 14 February 2017
Accepted 12 June 2017
Available online 19 June 2017

Keywords:
Ballastless slab track
Monolithic concrete slab
Workability of fresh concrete
High-performance concrete
Superplasticizer
Quartz microfiller

ABSTRACT

The concrete track-supporting layer and the monolithic concrete slab of ballastless track systems are made in-situ. For this reason the concrete mixtures of high workability should be used. Influence of the sand kind, the quartz microfiller fineness and quantity as well as quantity of superplasticizer on workability of fresh concrete and durability of hardened concrete is shown. The compositions of the high-workability concrete mixtures with lower consumption of superplasticizer are developed. The results of the research can be recommended for high performance concrete of ballastless slab track.
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1. Introduction

At present the ballastless track systems concepts are being developed all over the world. The advantages of such structures are described by (Esveld, 2010) and can be summarized as follows: reduction of structure height; lower maintenance requirements and hence higher availability; increased service life; high lateral track resistance which leads to the future speed increases in combination with the tilting technology and the absence of problems with churning of ballast particles at high-speed.

A concrete slab replaces the ballast in the ballastless slab track. This track structure has been widely used in high-speed railways in Japan, Germany, France and China as shown by the authors (Harada, 1976; Gao et al. 2013; Liu et al. 2011). Currently the most known slab track systems are: Rheda, Züblin and other variants (Germany); Stedef, Sonneville Low Vibration (France); Walo (Switzerland); Edilon block track (Netherlands); Shinkansen slab track (Japan, South Korea); IPA slab track (Italy); ÖBB-Porr (Austria); Embedded Rail Structure (Netherlands); China Railway Track System (CRTS).

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Peer review under responsibility of King Saud University.

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The slab track needs the low-maintenance. However, the subgrade layers must be homogenous and capable of bearing the loads imposed. The slabs can be made as the precast or in-situ concrete. The high level of investment is required and it prevents widespread use of slab track on open lines in Russia. The use of more efficient construction methods, concrete compositions can reduce construction costs further.

Configurations of ballastless track slabs vary throughout the world due to the different developments and can be individually adapted to the specific requirements and the individual constraints of each project. The basic system structure consists of modified bi-blocks which are obtained from halves of prestressed reinforced concrete sleepers. These bi-blocks are reliably embedded in a monolithic concrete slab. Concrete slabs are placed on concrete track-supporting layer. To assure the required durability the minimum strength of the concrete layer must be 30 MPa for samples-cubes and 37 MPa for samples-cylinders. (Rheda 2000, 2017). The prestressed reinforced concrete structure must be adapted for decreasing the freezing destruction. The CRTS III RUS ballastless slab track is being developed by the Chinese companies for the operation on the pilot section of the Russian railway. The CRTS III RUS is being made for the VNIIZhT experimental ring in Shcherbinka station for testing in 2017–2018 years (VNIIZhT, 2017).

The monolithic concrete slab is present in the structures of ballastless track of different developers. As a rule the concrete track-supporting layer and the monolithic concrete slab are made in-situ. For this reason the concrete mixtures of high workability should be used. There are several factors affecting the workability of concrete mixtures: the properties of Portland cement, properties

http://dx.doi.org/10.1016/j.jksues.2017.06.004
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of aggregates, presence of superplasticizer etc. Inappropriate choice of one of concrete components can lead to the increased consumption of superplasticizer or water, which increases the construction cost and reduces the concrete strength.

The combined effect of the properties of Portland cement and superplasticizer are shown by the authors (Smirnova, 2016; Zhang et al., 2015; Li et al., 2014; Lange et al., 2014). The influence of some mineral fillers on enhancing the workability of fresh concrete is shown in papers (Alonso et al., 2013; Burgos-Montes, 2012; Hallal et al., 2010; Ezziane et al., 2014). The increase of plasticizing effect of the superplasticizers with some mineral fillers are stated in the papers (Petrova and Smirnova, 2010, 2014; Petrova et al., 2011; Smirnova and Petrova, 2013; Elyamany, 2014; Makarevich and Smirnova, 2015). Increase of the dynamic strength characteristics is shown in paper (Kharitonov et al., 2015). However, the use of mineral fillers in concrete of railway structures requires justification and comprehensive research.

Among the many mineral additives for using in concrete of ballastless track one can offer the quartz filler. Unlike many mineral additives quartz filler allows to improve simultaneously: density of cement matrix by optimizing the granular mixture; cement matrix properties by pozzolanic properties; cement matrix properties by reducing water-to-binder ratio in plasticized cement paste. However, these issues of the positive influence of quartz filler on concrete properties were considered in the scientific literature separately. The optimum quartz filler quantity and fineness were stated for each individual property.

In the papers (Juhart et al., 2014, 2015; Mittermayr et al., 2015) it was found that not only packing density but also the water demand and the superplasticizer amount are crucial for the development of eco-mixes. The optimal packing of components that consists of aggregates, cement, microfillers with particles of different sizes, is not only important: workability properties of concrete play an essential role (Tikkanen et al., 2011).

Cement pastes and mortars have been analysed with the replacement to Portland cement by 15, 20, 25% of the ground dune sand with fineness of 5800 cm^2/g in the paper (Arroudj et al., 2017). Workability of these mortars containing 2% of superplasticizer was almost the same as the workability of the reference mortar without ground sand. In the long term (60 days) the mortars with 25% ground quartz sand developed the same strength as reference mortar.

The study (Kumar, 2016) revealed that quartz sand (as fine aggregate) can be used for developing Ultra High Strength Self Compacting Fiber Reinforced Concrete by reducing the water content and obtaining the required flow properties.

In the paper (Bumanis and Bajare, 2017) it was found that the application time factor of ground sand in cement mortar has the critical impact on mortars compressive strength: the greatest strength of the cement mortar was detected when the ground sand was applied in the mixture right after milling. It was concluded that the instant application of the ground sand (fineness d_{10} = 8,5 μm, d_{50} = 41 μm, d_{90} = 81 μm) could increase the compressive strength of cement mortar up to 20% if the ground quartz sand is used immediately as partial sand replacement up to 10 wt% in cement mortar. Two days old ground sands applied in cement mortar reduced the increase of compressive strength but was still higher (5 to 11%) compared to the reference mixture while the 28 days old ground sand deteriorates the compressive strength up to 4%.

There are no results on the effect of the quartz filler age (from the moment of grinding) on the plasticizing effect of superplasticizers in literature. In this case one of the objectives was the study of this fact.

Some microfillers can increase the plasticizing effect of superplasticizers. The compositions of high-workability concrete mixes with lower consumption of superplasticizer should be developed for concrete slab of ballastless systems.

Thus, in the above-reviewed papers the directions of the influence of the quartz filler (with fineness similar to Portland cement fineness) on the individual properties of fresh or hardened concrete were studied. The optimal grinding fineness and quantity of the quartz filler to improve certain properties of concrete were specified in the above papers. The aim of this research is a comprehensive approach to the selection of quartz microfiller quantity and fineness for slab concrete of ballastless track. With this approach, the influence of microfillers on properties of fresh and hardened concrete is taken into account with the maximum economy of Portland cement and superplasticizer since the transport facilities require large volumes of concrete.

Properties of fresh and hardened concrete made of local materials were investigated in the paper including properties that determine the durability of concrete. One of the objectives of this paper is to identify the possible ways to reduce the consumption of expensive components of the concrete mixtures.

The differences between the prices of mineral fillers are remarkable. The quartz powders can be more expensive than the Portland cement (Tikkanen et al., 2011). The high cost of the quartz powders is mainly explained by the small production volumes of these mineral additives. Quartz is the major form of pure silica in nature and it is a very hard material with hardness of seven on the Mohr's scale and density of 2.65 g/cm^3 (Aravindhan, 2016). The improvement of grinding technologies should lead to reducing the cost of the quartz microfillers. Modern grinding equipment is used in this research such as a centrifugal-elliptical mill and a centrifugal dynamic classifier. The classifier is designed for separating the filler particles in the air flow by size, density and shape with the aim to precipitate very fine fractions of the total volume of microfiller. Using the classifier reduces the energy consumption of grinding.

2. Materials and methods

The microfiller of ground natural quartz sand with content of SiO_2 more than 94% (Luga field, St. Petersburg) was used in the research. The AC100 centrifugal-elliptical mill (mill class "Activator C") of the Finnish Oy CYCLOTEC Ltd company was used to obtain fine particles.

The working capacity of the ball mill is directly proportional to the specific weight of grinding balls. The idea of replacing the grinding balls of larger specific weight by using centrifugal forces is used in a centrifugal-elliptical mill. This mill consists of two or more parallel cylinders rotating on a circle around a common axis. The combination of the centrifugal force generated by the rotating of cylinders around the main axis and the centrifugal force generated by the rotating of cylinders around their own axis, allows to increase the grinding load and to obtain finer powder. The use of an efficient classifier for separating filler particles in the air flow makes it possible to adjust the particle size distribution of mineral powders. The centrifugal-dynamic classifier of the "Lamel-777″ company was used in this research (Air centrifugal dynamic classifiers, 2017).

Crushed granite of nominal maximum size of 20 mm was used as coarse aggregate. The size distribution of two kinds of the fine aggregates (marked as sand 1 and sand 2) and their chemical compositions are presented in Tables 1 and 2.

Microfillers were obtained by milling sand 1 and sand 2 and marked as S1, S2a, S2b. The microfillers S2a and S2b differed by fineness. The particle size distributions of microfillers were estimated by using the "Analysette 22" analyzer and are shown in Table 3.

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