Construction and Building Materials 122 (2016) 736–742

Contents lists available at ScienceDirect

Construction and Building Materials

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

Ultra-high strength concrete made with recycled aggregate from sanitary ceramic wastes – The method of production and the interfacial transition zone

Zegardło Bartosz [a], Szeląg Maciej [b,*], Ogrodnik Paweł [c]

[a] Siedlce University of Natural Sciences and Humanities, Department of Quantitative Methods and Spatial Management, Stanisława Konarskiego Str., 08-110 Siedlce, Poland
[b] Lublin University of Technology, Faculty of Civil Engineering and Architecture, 40 Nadbystrzycka Str., 20-618 Lublin, Poland
[c] The Main School of Fire Service, Faculty of Fire Safety Engineering, 52/54 Słowackiego Str., 01-629 Warszawa, Poland

HIGHLIGHTS

- Ultra-high strength concrete production was described, using ceramic aggregate.
- Mechanical and physical properties were tested.
- SEM was used to evaluate the interfacial transition zone.
- Apparent increase in adhesion of ITZ was modeled.

ARTICLE INFO

Article history:
Received 9 January 2016
Received in revised form 5 April 2016
Accepted 21 June 2016

Keywords:
Ceramic aggregate
Ultra-high strength concrete
Interfacial transition zone
Cement paste

ABSTRACT

The article describes a new model of ultra-high strength concrete (UHSC) production. It was assumed that the components will be generally available in the concrete plant such as cement, plasticizing admixtures and pozzolanic additives. Aggregate used will be a post-production sanitary ceramic wastes, selected to the two fractions of 0–4 mm and 4–8 mm. The goal of this study was to produce concrete with the highest strength parameters using iterative design method of concrete mix. For so obtained concrete, its basic physical and mechanical parameters were examined, such as: compressive and tensile strength, bulk density, water absorption, water permeability and frost resistance. The examined parameters were compared with results obtained on the reference samples made with the same ingredients, only used aggregate was gravel (0–4 mm) and basalt (4–8 mm). In addition, the interfacial transition zone (ITZ) between cement paste and aggregate (ceramic and basalt) was analyzed, using Scanning Electron Microscope (SEM). On this basis, conclusions on the impact of the ITZ's microstructure on the final characteristics of concrete were made. Own model of cement paste adhesion to the ceramic wastes aggregate was developed.

1. Introduction

Search for concrete mixtures' recipes with higher endurance characteristics lasts for many years. A lot of research works are devoted to search for the optimal composition as well as the optimal terms of concrete manufacturing, which has an impact on final concrete properties. Compression during formation [1], maturing at elevated temperatures [2], use of admixtures and additives [3], specific graining selection [4] – are just some solutions that are currently used in the production of concrete.

From the beginning of this century in concrete technology development of UHSC [5–7] is enhanced. These concretes are characterized by compressive strength above 120 MPa. Their ingredients are chosen in such way that the composite reach its parameters without special treatment (like compression or autoclaving) – only normal hardening. The amount of the cement content is much higer compared to the ordinary concrete [8]. The latest trend in the design of UHSC is to use the nanofillers – particularly nanosilica [4,9–18]. The researchers highlight the specific properties of this nanofiller with two-level effect on cementitious composite. Firstly, grains of the nanosilica are filler of cement paste's structure. Secondly, they are a reactive component, which strengthens the physico-chemical structure of the cement paste. The use of this

* Corresponding author.
E-mail addresses: bart.z@wp.pl (B. Zegardło), maciej.szelag@pollub.pl (M. Szeląg), pawel-ogrodnik@wp.pl (P. Ogrodnik).

http://dx.doi.org/10.1016/j.conbuildmat.2016.06.112
0950-0618/

additive increases the compression and tensile strength of concrete, decreases water sorption and porosity [8].

When analyzing the use of UHSC [5,19] and the market demand for the composite, scientists are seeking solutions to its mass production. The study [20] describes a way to produce a concrete with strength more than 150 MPa. The authors using water/cement (W/C) ratio of 0.14–0.18 established the maximum amount of the binder at the level of 900 kg/m^3. Additionally, large amounts of mineral additives in the form of blast-furnace slag and lime powder were used. Using the traditional methods of production, formation, and maturation the composite suitable for industrial applications was obtained.

A relatively new trend in the concrete's production is manufacturing based on application of recycled ceramic aggregates. Currently conducted research on the use of ceramics (in particular red one) are focused mainly on the ecological effect [21–33]. Their main goal is to find a potential way to apply ceramic wastes, without emphasis on getting the specific concrete's characteristics. The analysis carried out on the concretes made with ceramic waste aggregate can be found in a limited number of studies [31,34–38]. The researchers used sanitary ceramic wastes as a substitute for the selected aggregate fractions. The best results [37] were received for concrete, in which coarse aggregate was replaced with ceramic aggregate – increase in the compressive strength were greater than 11%.

Authors of this article in earlier studies [39] pointed out the benefits of using ceramic waste aggregate. The mechanical characteristics of obtained concretes (in whole contained ceramic aggregate) reached 90.5 MPa – compressive strength; 9.54 MPa – tensile strength. These concretes were designed for use in high temperatures and for their manufacture high-quality alumina cement was used.

The goal of the study was to create a concrete with the highest strength parameters, using aggregate entirely derived from sanitary ceramic wastes. In addition, the assumption was to use the ingredients commonly used for the mass concrete production, so that the designed concrete was possible to manufacture without special treatment or components.

The research program involved in the design of concrete mix, which was carried out by experimental method [40], and examine the fresh mix and hardened composite properties: consistency, compressive and tensile strength, bulk density, water absorption, water permeability, and frost resistance. The reference samples were also made, based on the same ingredients. Only aggregate was a mixture of gravel and basalt – aggregates commonly used for the high strength concretes production.

In addition, the interfacial transition zone between cement paste and aggregate was analyzed (using SEM). This analysis has allowed an assessment of the texture's type of ceramic and basalt grains. The impact of the ITZ on the concrete's properties was determined, and own model of cement paste adhesion to the ceramic aggregate was developed.

2. Materials used in the study

The aggregate used in the study was obtained from sanitary ceramic wastes. The material in manufacture was classified as defective, due to the occurring cracks, dents etc. Ceramic wastes (Fig. 1a) were subjected to crushing in jaw crushers, which allowed for the selection the resulting aggregate into two fractions – 0–4 mm and 4–8 mm (Fig. 1b).

The manufactured aggregates were tested under a series of standard tests [41–45], which were described in the paper [39]. Analysis of aggregate characteristics allowed to believe that it will be a suitable aggregate to manufacture UHSC.

A mixture of sand and gravel (0–4 mm fraction), and basalt (4–8 mm fraction) was used for reference samples. The basic properties of aggregates used in the study are shown in Table 1. The particle size distribution of gravel-basalt and ceramic aggregate is shown in Fig. 2.

The output for the design of the concrete mix (in terms of ingredients selection) was the concrete's recipe of C45/55 class, prepared by concrete plant. The CEM I 42,5N – SR 3/NA cement was used, which is characterized by initial setting time – 233 min, end of setting time – 291 min, water demand – 27.5%, specific surface area – 3688 cm^2/g, early compressive strength (after 2 days) – 23.9 MPa, standard compressive strength (after 28 days) – 55.9 MPa. In addition, the cement has low content of alkali, high resistance to aggressive chemical agents, which makes it popular in manufacturing of industrial concrete.

As an admixture the ISOFLEX 7130 superplasticizer (based on polycarboxylic ethers) was used. The microsilica was used as a pozzolanic additive, which was obtained in process of gas purification of furnaces used in the production of alloys containing silicon. Microsilica due to the relatively low price and easy availability is one of the ingredients, which in industrial concrete manufacturing is used to create concretes with special properties i.e., high strength, resistant to frost, high temperature, and chemical aggression.

3. Mix design method

The authors' experience in the design of concrete made with recycled ceramic aggregate [39] have shown that the most effective method to design this type of composite is the experimental method [40]. Methods based on a basic formulas [46] did not produce the expected results. Ceramic aggregate with absorption about 1.5% [39] absorbed too large amounts of cement paste and concrete mix was becoming leaky.

In accordance with the guidelines [46] firstly, the quantitative selection of cement paste's components was made. The ingredients were mixed in the proportions suggested by manufacturers. Microsilica was added to the cement in an amount of 10% by weight. Superplasticizer was added to water in an amount of 1.5% by weight. To a mixture of cement and microsilica, the liquid compounds were added gradually, after which cement paste was compacted. The mixing process started as proposed in [4] W/B (water/binder) ratio equal to 0.15. Subsequent attempts were held for W/B equal to 0.2, 0.25, 0.3, 0.32, 0.34, and 0.36. Water, during each of the mixing was dosed evenly with small portions. Mixing on this stage was carried out with the low-speed mixer, in order to reflect the mixing process of industrial concrete. Only with a W/B equal to 0.36, it was possible to uniformly thicken the cement paste. The wetted grains of binder connected with each other and were formable in hands.

Preparation of aggregate was based on iterative fractions selection, in which the goal was to achieve the maximum bulk density. The procedure of the fractions selection was identical to that presented in paper [39]. The aggregate mixture was used in proportion of 1:0.4 (0–4 mm to 4–8 mm). This proportion was optimal from the point of view of aggregate mix tightness.

The concrete mix designing based on obtained cement paste and ceramic aggregate was conducted in an iterative manner also [46]. Into the prepared mixture of aggregate, the cement paste was added in cement paste/aggregate proportions of successively 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, and 0.5. Then the mixed ingredients were compacted. The cement paste/aggregate proportion equal to 0.5 was the first, in which cement paste was able to fill voids between aggregate's grains. For the remaining proportions, empty spaces between grains were visible.