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The impact of primary sludge from paper industry on the properties of hardened cement paste and mortar

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HIGHLIGHTS

- Increasing content of PS in cement paste, the process of hydration is retarded.
- Increasing content of PS, density of mortar and the cement content were decreasing.
- PS waste may be used for mortar by replacing up to 5% of cement or fine filler.

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ABSTRACT

In the paper, the impact of paper production waste (primary sludge, or PS) on the properties of cement pastes and mortars is discussed upon. Some specimens were formed with fine PS fraction that replaced a part of cement content in them (5%, 10%, 15%, or 20%); in other specimens, coarse fraction of sludge (2/4) was used and a part of content of fine filler (sand) was replaced by PS. The properties of mixtures, such as water content required for cement paste of normal consistence, the setting time, exothermic temperature, flow diameter and plunger penetration, were established. In addition, the properties of hardened mortar, such as its density, flexural strength and compressive strength, were established. The microstructure of hardened specimens was examined as well. It was found that PS retarded hydration processes and reduced exothermic temperature; in addition, it reduced the flow diameter and the plunger penetration. While assessing the properties of hardened mortar, it may be stated that 5% PS waste might be used for replacement of a part of cement content.

1. Introduction

In course of paper production, different kinds of waste are formed in each phase of production. Most frequently, waste from paper production is divided into 4 parts: rejects, deinking sludge, primary sludge and secondary (or biological) sludge [1]. The waste from paper production is mostly presented by primary sludge. Because paper production industry is developed world widely, very large quantities of the said waste are generated. "This sludge is generated in the clarification of process water by kidney treatments, e. g., dissolved air flotation. The sludge consists of mostly fines and fillers depending on the recovered paper being processed and it is relatively easy to dewater" [2].

Primary sludge distinguishes itself for high humidity and high content of cellulose as well as variable chemical composition [3]. In the work [4], chemical and mineral composition of dried primary sludge waste is presented: cellulose ($C_{12}H_{20}O_{10}$), calcite ($CaCO_3$), muscovite $(Al_2O_3)_3(SiO_2)_6K_2O(H_2O)_2$, talc $(Mg_3Si_4O_{10}(OH)_2$, kaolinite $Al_2O_32SiO_22H_2O$, and quartz SiO_2. It was established that waste from paper production is classified as non-hazardous waste [5–8].

This waste may be used for production of various building materials, such as cement, ceramics, zeolite synthesis, waterproofing, lightweight matrices et cetera. It was found that primary sludge activated at a high temperature (500–900 °C for 2–5 h) distinguishes for high pozzolanic properties, and kaolin presented in it transforms into metakaolin [4,9]. It was established that if a part of cement content (10–20%) is replaced by the said thermally processed waste, the compressive strength remains practically the same; however, frost resistance of hardened cement mortar increases considerably [10]. The authors [11] found that paper production waste (primary sludge) might be used for cement production. The scientists [12,13] established that if a part of cement content in mortars is replaced by primary sludge ash, the compressive strength of hardened mortar decreases after 28 days; however,

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it begins increasing again after 90 days. The increasing starts when 10% the waste is used [13]; in addition, the authors [14] found that if 10% of waste (where the content of the predominating oxide CaO is 46.2% and the loss of ignition (L.O.I.) – 38.5%) is added to the mortar instead of cement, the strength remains the same as of the reference specimen; however, waste utilization takes place. The same authors also established the impact of primary sludge waste on the strength of hardened concrete. It was found that the strength had decreased in all the cases: in case of 10% content of waste, the strength decreased approximately by 20% and in case of 20% content of waste – about 35%.

It was established that if PS waste has been held at 650 °C for 2 h, it may be used in construction industry [15].

Scientists from India [16] used paper sludge ash (primary sludge after thermal processing at a high temperature) in production of concrete replacing the said waste 5%, 10%, 15%, 20% content of cement. The predominating chemical elements of waste included: Si – 60.6%, Ca – 14.9% and O – 15.8%. In course of the research, it was found that increasing the waste content in the mortar required higher content of water; in addition, the slump decreases, the density becomes less, the water infiltration rate grows and the compressive strength, when 5% of cement content is replaced by the waste, increases by about 15%. However, on further increasing the waste content, the compressive strength was decreasing. In addition, the impact of such a waste on the properties of wood-wool cement boards had been examined [17] and 5–20% content of waste was recommended for use.

In their paper, the authors from UK [18] provided the following chemical composition (the predominating oxides include: CaO – 61.2%, SiO_2 – 21.2% and Al_2O_3 – 12.6%) and mineral composition (gehlenite, calcite, lime and mayenite) of primary sludge ash. The said scientists replaced 2%, 4%, 6%, 8%, or 16% of cement content with the above-mentioned waste and found that the density and the compressive strength of hardened concrete were decreasing with increasing the waste content in the mortar; however, water tightness of concrete increases dramatically.

The scientists [19] investigated opportunities of using paper production waste in asphalt production and found that ash obtained of primary sludge might be used for cold asphalt production; however, dregs because of their properties did not show any positive changes of the properties of asphalt.

The scientists [20,21] investigated opportunities of using paper production waste in production of ceramics. It was found that upon using paper production waste where the predominating oxide of chemical composition is CaO (approximately from 40% to 56%), and L.O.I. is from 41% to 46%, it would be possible to produce ceramic bricks and such a production would be attractive both in the technological and the environmental aspects, because the produced bricks distinguish for improved mechanical properties; in addition, use of natural resources (particularly, clay) is reduced and waste processing takes place [20]. Other authors [21,22] established that paper production waste might be used in production of ceramic bricks, thus saving clay resources; however, such ceramic bricks distinguish for lower compressive strength, higher porosity and higher water infiltration rate. When porosity increases and the density decreases, the thermal conductivity coefficient decreases as well. So, the said waste may be used in production of energy-efficient blocks.

In the research [23], it was investigated whether paper production waste was usable in gypsum products. Different compositions and different mixture preparation ways (i.e. using dried waste or using waste mixed with water) were chosen. The best results were obtained when dried waste was used; first of all, the dry waste was mixed and the water was added.

Analysis of literature shows that the most researches were performed with PS waste, which was burned at higher than 500 °C temperature and were analysed its impact on cement, ceramics, zeolite synthesis, waterproofing, lightweight matrices and et cetera properties.

The goal of our work was to examine the impact of paper production waste (primary sludge), which hasn't been heated at high temperature, on the physical and mechanical properties of cement mortar and to analyse possibilities of utilization of PS waste in cement mortar.

2. Materials

In the research, cement CEM I 42.5 R was used; its chemical composition is presented in Table 1.

Mineral composition of the cement: C_3S – 62.5%, C_2S – 16.9%, C_3A – 7.1%, C_4AF – 11.5% and 2% others (alkaline sulphates and CaO). The fine aggregate – sand conforms to the requirements of EN 12620. Fraction 0/2. Granulometric composition of sand is presented in Fig. 1.

It was determined, that PS bulk density of 0/0.63 fraction is 420 kg/m^3, and the density of coarse fraction 2/4–390 kg/m^3. According to the research methodology provided in [24], it was found that PS was an active additive of fraction 0/0.63. After seven days of hardening with lime in air and three days of soaking in water, the specimens remained hardened. In the beginning, PS was dried at the temperature of 75 °C for 48 h in laboratory stove SNOL, then crumbled by a gill crusher and screened through a sieve of an appropriate fineness. The waste was put in the mixture in a form of dry powder. The photo of PS is provided in Fig. 2.

In the paper, crumbled fraction 4/8, fraction 2/4 and fraction 0/0.63 of paper production waste are discussed upon.

In one case, a part of cement content in cement mortars was replaced with the waste (the mark C) of the fraction 0/0.63, while in the other case, a part of sand content was replaced with coarser waste, fraction 2/4 (mark S). While choosing the compositions, the results of investigations carried out by other scientists, namely, that the maximum content of PS waste can be 20%, were taken into account. The compositions of cement mixtures are provided in the

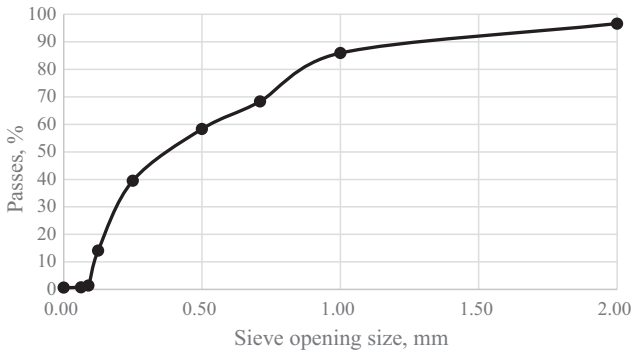

Fig. 1. Granulometric composition of sand.

Table 1
Chemical composition of cement.

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	Cl	L.O.I.
63.2	20.4	4.0	3.6	2.4	0.9	0.2	3.1	0.05	2.15