Drainage Concrete Based on Cement Composite and Industrial Waste

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Abstract The ongoing development of urbanization of our landscape has resulted in continuous demand for building materials, which are even nowadays produced mainly from primary natural resources. The continuous reconstructions and modernizations of already built-up areas are the cause of the production of construction

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waste which, for example, in Europe represents ¼ of the volume of all waste materials. Such a trend is inconsistent with sustainable development and considerate impact on the environment. The contemporary society is aware of these adverse impacts and it actively participates in the integration of construction waste back into production. Thanks to the systems of recycling, construction waste can return to the building industry as a fully valuable building material. The production of shaped pieces from grey cellular concrete after the autoclave process results in the creation of residual material in the form of waste blocks (rubble). This waste material is stored in dumps. The presence of these dumps has an adverse effect on the surrounding environment. This article presents the first results of a basic research dealing with the treatment process of waste cellular concrete rubble by means of a crushing process and its subsequent use as filler in the production of new porous concretes. The article presents 3 basic recipes of porous concrete, where 100 % of the filler was replaced with crushed porous concrete rubble with the fraction of 0/6 mm. The proposed recipes have been tested in regards to: density of fresh concrete mixture, concrete mixture consistency, strength, and thermal conductivity coefficient.

Keywords Porous concrete · Cellular concrete rubble · Strength · Thermal conductivity coefficient

1 Introduction

Recycling and use of industrial waste in different areas minimize the production of waste, its disposal costs and they protect the environment. This topic is very relevant in terms of research and development of new materials. The issue is especially the use of industrial waste as a secondary raw material in the segment of building materials, particularly concrete. There are known results of the use of fly ash in the production of concrete, as a partial replacement of cement [1, 2], and the production of copolymers [3]. The properties of concrete based on blast furnace slag, as a partial replacement of Portland cement and concrete based on steel slag and as a partial replacement of natural aggregates, are described in [4, 5]. The properties of porous concretes based on natural aggregate with the fractions of 13/20, 5/13, 2.5/5 mm are described in [6]. There are also porous concretes based on latex binder in combination with coarse aggregate and river sand [7]. The use of waste concrete rubble as a complete or partial replacement of the filler in concrete mixtures can be presented as an example of an effective treatment of construction waste. This recycling method turns waste rubble into synthetic aggregate, which is an alternative to natural aggregate. This leads to a balanced utilization of natural resources and helps to tackle the issue of waste management. A specific example of the possible use of recycled waste shaped pieces from grey cellular concrete is porous concrete. It is a lightweight concrete (density after drying at 105 °C reaches the values of 800–2000 kg·m^{-3}), which is specific due to its porosity. Porous concrete typically achieves lower strength classes than plain concrete. The production makes use of porous or dense aggregate. The individual grains are bonded by a binder film on each grain and there is a large volume of air gaps among them [8]. The concrete may consist of one type of fraction or more fractions of small and coarse aggregate, cement, water and optional additives. One can also come across the name "drainage concrete" [9]. In the world, porous concrete is used as a top water-permeable layer on pedestrian foot-paths or roads, where rain water is absorbed in the soil. This leads to a more moderate and more continuous outflow from urbanized areas during tidal rains, improvement of groundwater level and relief of the flow in sewerage systems [10–12]. Another possible application of porous concrete is in partition walls, non-bearing walls, shaped pieces, grass tiles, decorative elements for walls and fences. It is used in places requiring thermal insulation and acoustic insulation.

The aggregate (filler) used in porous concrete can be:

(a) From natural sources:

- Keramzite—ceramic porous aggregate (produced by burning and expansion of natural clay) used in lightweight porous concrete. It is also known under the brand name Liapor.
- Expandit—lightweight porous material (produced by expansion of slate) used as artificial aggregate in concrete.

(b) From industrial waste materials:

- Agloporit (produced by burning fly ash from power plants). It is also know under the brand name Lytag.
- Foamed slag (sudden cooling of hot liquid slag by water).
- Cinder (waste of incineration of solid fuels in grate furnaces).
- Brick rubble (waste from brick production, recycling of brick rubble).

2 Materials and Methods

2.1 Artificial Filler to Concrete from Industrial Waste Materials

Generally, the production of grey cellular concrete follows the rule that the siliceous materials (fly ash from coal combustion) together with burnt lime and cement, or other additives are broken down in special mixers with water, border sludge and a gassy agent (aluminium powder) into a liquid slurry. It is then poured into moulds, where the actual loosening will take place—proofing followed by hardening. De-moulding of the moulds is the next process and the hardened material is cut into the required shapes. Curing of grey cellular concrete takes place in autoclaves at higher pressure and temperature. This environment facilitates an effective bonding of the individual components of the concrete mixture. The final product of the production process is a porous shaped piece for very precise walling. The material is safe, it has low density, it is a good thermal insulator, and it is soundproof and permeable. The compressive strength of grey porous concrete is 3.2 MPa.

Nonconforming shaped pieces occur during the production of grey cellular concrete—these are rejects that become the waste material, which is stored in dumps in the production plant area (see Fig. 1).

Figure 2 shows a scheme of treatment of rubble from autoclaved cellular concrete from Fig. 1.

Figure 2 clearly shows that the first stage of mechanical treatment of waste autoclaved cellular concrete is a jaw crusher, where the output is rubble with a maximum grain size of 50 mm. The crushed rubble subsequently goes through a swing-hammer crusher, where the output is pulp with a maximum grain size of 6 mm. Thanks to the absence of foreign substances, we can eliminate the sorting process. The resulting cellular concrete pulp with the fraction of 0/6 mm is used as new filler in the developed porous concrete.

Fig. 1 Waste blocks (rubble) from the production of autoclaved cellular concrete

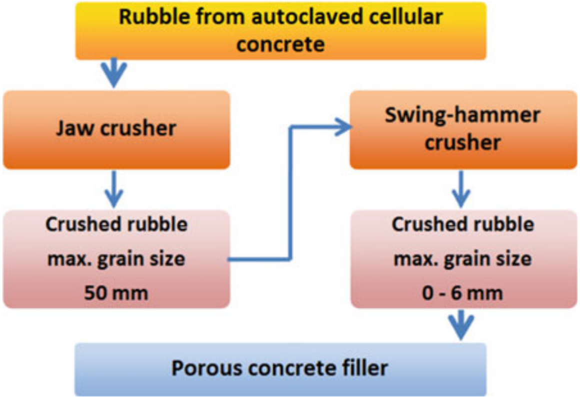

Fig. 2 Scheme of the treatment of waste rubble from autoclaved cellular concrete

2.2 Porous Concrete Components

Crushed rubble from autoclaved grey cellular concrete with the fraction of 0/6 mm was used as the new filler in porous concretes based on industrial waste. Portland cement CEM I 42.5 R from Cement Hranice, a.s. was used as the binding component. Water from the water supply network, i.e. drinking water, was used as the mixture water.

2.3 Preparation of Porous Concrete

The preparation of the experimental mixtures according to the proposed recipes was performed in M80 forced circulation mixer from FILAMOS s.r.o. company. The mixing is carried out by several arms that also ensure that the mixture is scraped from the side and the entire bottom of the mixing tank. The mixture filling is carried out through a sieve in the mixer lid, which is equipped with a shredding comb for bagged mixtures. The mixed material is discharged by turning the sliding segment at the bottom of the tank. The technical parameters of the mixer are shown in Table 1.

2.4 Methods Used to Determine the Physical Properties

The crushed rubble of grey autoclaved cellular concrete was tested for powder density and porosity according to CSN EN 1097-3 [13]. The powder density of freely poured aggregate is determined by weighing the volume of a 5 l standard cylindrical container filled with porous concrete rubble. The pouring of the material into the container is carried out from a minimum height to avoid the compaction of the sample. The resulting value is the average of three measurements.

The density of autoclaved grey cellular concrete was determined according to CSN 72 1171 [14]. The grain density is calculated from the ratio of weight and sample volume. The weight is determined by weighing the water-saturated and surface-dried testing sample backfill and, again, by weighing after drying in a drying plant. The volume is determined from the weight of the water displaced during the application of the pycnometric method. The absorbing power is based on

Table 1 Technical parameters of M80 mixer

Tank volume [l]	111
Max. used volume [l]	69
Electromotor output power [kW]	2.2
Voltage [V]	400
Mixer rotations [rot/min]	47
Max. material grain size [mm]	10
Weight [kg]	137

the increase in weight of the aggregate sample dried in a drying plant, as a result of water penetration into the cavities accessible to water.

The porosity of autoclaved cellular concrete pulp was determined according to CSN EN 1097-3 [13]. It was calculated from the powder density of freely poured aggregate and the grain density.

The geometric properties of cellular concrete pulp were determined by a sieve analysis according to CSN EN 933-1 [15]. The test is based on sorting and separating the material by means of a set of sieves into several grain size parts with decreasing particle size. The mesh size of the sieves and the number of sieves are selected according to the type of sample and the required accuracy. The standard basic set of sieves consists of sieves with square holes with the sizes of: 0.063, 0.125, 0.25, 0.5, 1, 2, 4, 8, 16, 32, 64 and 125 mm.

The consistency of the porous concrete mixture based on autoclaved cellular concrete rubble was examined by a slump test according to CSN EN 12350-2 [16]. Fresh concrete was compacted in a mould of blunted cone shape (diameter of the bottom base was 200 mm, the upper base was 100 mm, the height was 300 mm). The concrete consistency is indicated by the slump distance of concrete after lifting up the blunted cone.

The strength of the newly developed porous concrete was tested on test specimens in the shape of a cube, with the dimension of 150 mm, according to CSN EN 12390-3 [17] after 3, 7, 14 and 28 days.

The thermal conductivity coefficient λ of porous concrete was determined by a measuring device ISOMET 2114 from Applied Precision company. It is a device designed for a direct measurement of the thermal conductivity coefficient of solid, loose or liquid materials. The measuring method is non-stationary and is based on the analysis of the course of the time dependence of the thermal response to a pulse of heat flux of the examined material. The heat flux is generated by a device probe by means of diffused electrical power of resistor in the material. The condition for correct results is a conductive connection between the probe and the measured material. The measured value of the thermal conductivity coefficient can be read directly from the instrument in [$W \cdot m^{-1} \cdot K^{-1}$]. The determination of the thermal conductivity coefficient was performed on 150 mm cubes. After 28 days of curing, the sample was placed in a drying oven, where it was dried at 105 °C ± 1 °C for 48 h. The dried sample was then placed in an exicator, and after cooling to a room temperature, it was measured with a surface probe with the measuring range from 0.04 to 2.00 $W \cdot m^{-1} \cdot K^{-1}$ located in the middle of the test specimen surface.

3 Results and Discussion

Table 2 presents the determined physical properties of cellular concrete pulp, which was obtained by treatment according to the scheme presented in Fig. 2. The pulp is used as a complete replacement of natural aggregate (filler) in the production of porous concrete.

Table 2 Physical properties of crushed pulp of autoclaved cellular concrete with the fraction of 0/6 mm

Parameter	Measured value
Powder density of freely poured aggregate	543 kg·m^{-3}
Density	844 kg·m^{-3}
Absorbing power	44.4 %
Porosity	35.6 %

The results of the sieve analysis of cellular concrete pulp are presented in Figs. 3 and 4. A set of sieves with square holes with the dimensions of: 0.063, 0.125, 0.25, 0.5, 1, 2, 2.8, 4, 5.6 and 8 mm was chosen for the actual analysis. Cellular concrete pulp consists mainly of about 40 % of grain size of 1–2 mm, 18 % of grain size of 2–2.8 mm, 13 % of grain size of 0.5–1 mm, 10 % of grain size of 0.063–0.125 mm.

Three basic recipes, with different doses of cement and water-cement ratio, were designed on the basis of the verification of the possibility of the use of waste

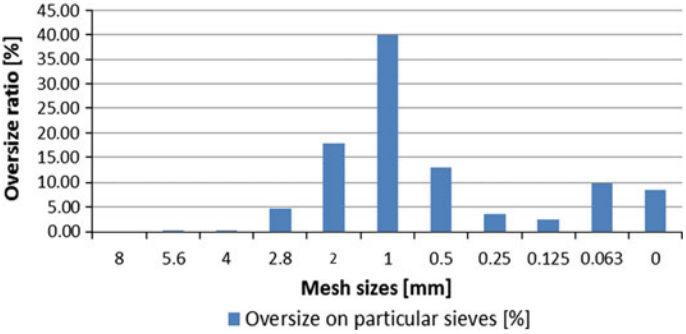

Fig. 3 Share of oversize cellular concrete pulp with the fraction of 0/6 mm on the individual sieves

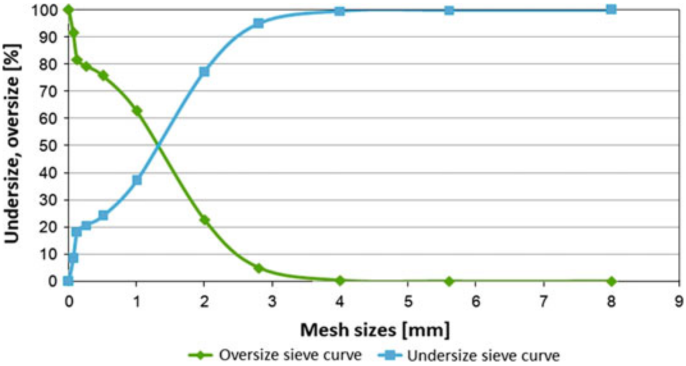

Fig. 4 Cumulative curves of grain fitness of cellular concrete pulp fraction 0/6 mm

cellular concrete pulp as a full replacement of natural aggregate in the production of porous concrete. The composition of the experimental recipes is shown in Table 3.

The purpose of the selected recipes is to determine the sufficient minimum amount of cement, while maintaining the porous structure, strength and good workability of the fresh concrete mixture.

18 test specimens were prepared from each recipe (150 mm cubes). The development of compressive strength of porous concrete was monitored after 3, 7, 14, 21, and 28 days. The results are presented graphically in Fig. 5. It is evident that the strength of porous concrete increases with the amount of cement, which was dosed at the amounts of 200, 300 and 400 kg per m^3. The highest values of compressive strength of 4.1 MPa porous concrete based on waste cellular pulp were achieved after 28 days in recipe no. 3.

In addition to the compressive strength of concrete, we have also monitored other properties of porous concrete. They were: the density of fresh concrete mixture, the consistency of fresh concrete mixture immediately after mixing (slump test), and the thermal conductivity coefficient λ. The results of these tested properties, together with the compressive strength of porous concrete after 28 days, are shown in Table 4.

Table 4 clearly shows that the value of density of fresh concrete mixture of porous concrete ranged from 1172 to 1241 $kg \cdot m^{-3}$, the slump values were in the interval of 2–4 mm, while a shearing failure occurred in recipe 1, see Fig. 6. It was

Table 3 Composition of experimental recipes on 55 dm^3 and 1 m^3 of final porous concrete

Components	Unit	Recipe 1		Recipe 2		Recipe 3	
		55 dm^3	1 m^3	55 dm^3	1 m^3	55 dm^3	1 m^3
Cellular concrete pulp	kg	29.8	543	29.8	543	29.8	543
Cement CEM I 42,5 R	kg	11.0	200	16.5	300	22.0	400
Water	kg	12.1	220	19.0	345	26.4	480
Water-cement ratio w	–	1.10		1.15		1.20	

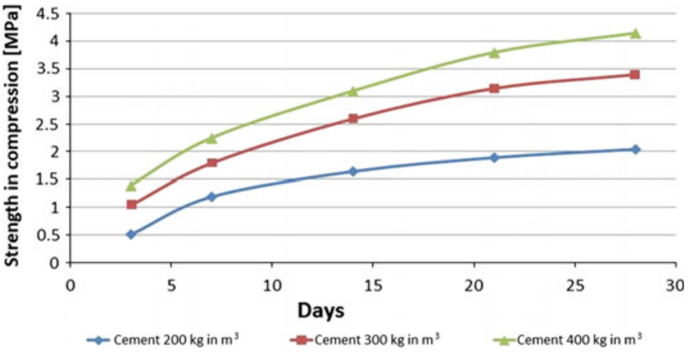

Fig. 5 Strength of porous concrete after 3, 7, 14, 21 and 28 days

Table 4 Test results of physical and mechanical properties of experimental recipes

Marking	Density of fresh concrete mixture [kg·m^{-3}]	Slump [mm]	Compressive strength after 28 days [MPa]	Thermal conductivity coefficient λ [W·m^{-1}·K^{-1}]
Recipe 1	1172	–	2.0	0.2020
Recipe 2	1203	4	3.4	0.2146
Recipe 3	1241	2	4.2	0.2269

Fig. 6 Shearing failure of cone during the slump test of recipe 1

caused by a small dose of cement, where the grains of cellular concrete pulp were not completely coated with cement sealant.

The thermal conductivity coefficient **λ** ranged from 0.2020 to 0.2269 W·m^{-1}·K^{-1}. It is evident that the increasing amount of cement in the concrete mixture goes hand in hand with the increasing value of the thermal conductivity coefficient.

4 Conclusion

Based on the achieved results, it can be stated that crushed waste rubble from autoclaved cellular concrete with a maximum grain size of 6 mm can be used as a 100 % replacement of natural aggregates in the production of porous concrete. The prepared concrete reaches density values of around 1200 kg·m^{-3}. The compressive strengths are as high as 4.2 MPa after 28 days, the slump is 2–4 mm, and the thermal conductivity coefficient λ reaches the values of 0.2020–0.2269 W·m^{-1}·K^{-1}.

The new feature of the presented solution lies mainly in the use of industrial waste created in the form of grey scrap blocks during the production of grey cellular concrete as new filler for porous concretes. This waste is stored in dumps in the production plant area or it is kept in municipal waste landfills, which is not in compliance with environmental protection and sustainable development.

Further addition of additives and admixtures into the recipes can lead to a significant improvement of the physical and mechanical properties of porous concrete. The future research will also be focused on monitoring frost resistance, shapes and sizes of pores of the newly developed porous concrete and the possibility of studying the topography of its surface.

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