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Waste of granite dust utilization in ultra-light weight concrete

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Abstract. In the article possibility to utilize granite dust in production of ultra-light weight concrete (≤800 kg/m3) is researched. Granite dust is a by-product of crushed granite, has very fine particles and high surface area. Due to very fine particles and high surface area, applicability of granite dust in concrete is limited. Mainly because granite dust increases W/C ratios and thus mechanical and durability properties tends to decrease. Ultra-light weight concrete, usually has very high W/C ratios, therefore in this type of concrete utilization of granite dust has favourable opportunity. In the research ultra-light weight concrete based on aluminium powder was created. Main mechanical and microstructure properties were researched and thermal conductivity coefficient was calculated. During experiment ultra-light weight concrete with 700 kg/m3 and up to 3.33 MPa was created. According to the experiment results, waste of granite dust can be properly utilised in production of ultra-light weight concrete blocks suited for one or two storages individual houses.

Keywords: ultra-light weight concrete, ULWC, granite dust

1. Introduction

Ultra-light weight concrete (ULWC) is a type of concrete which has density bellow 800 kg/m^3 [1]. Due to light density it relatively high strength it can serve as insulator and also will make lower load on the foundation. There are many types of ultra-light weight concrete: 1) lightweight aggregate concrete – this type of concrete is created by using porous lightweight aggregate of low apparent specific gravity (lower than 2000 kg/m^3); 2) Aerated, cellular, foamed or gas concrete – this type of concrete is created by introducing large voids within the concrete or mortar mass; these voids should be clearly distinguished from the extremely fine voids produced by air entrainment; 3) No-fines concrete - this type of concrete is created by omitting the fine aggregate from the mix so that a large number of interstitial voids is present; normal weight coarse aggregate is generally used [2,3]. In this research ultra-light weight concrete based on aluminium powder was created and partial of cement was replaced with granite dust waste.

In this case expansion of the concrete is obtained by adding aluminium powder to the water/cement mix. Manufacture process is without autoclave, however some external energy is required. The chemical reaction between cement and aluminium is the following: $2Al + 3Ca(OH)_2 + 6H_2O => 3CaO\ AL_2O_3\ 6H_2O + 3H_2$ [7]. As stated by the formula $3H_2$ is formed. The creation of these hydrogen bubbles causes the mix to expand thus density decreases. The dosage of aluminium powder typically depends on W/C ratio, cement, mixer type, used chemical composition, temperature etc.

Waste of granite dust is a by-product of crushed granite, due to very fine particles and surface area, inserts of clays, cannot be anywhere properly utilized, thus waste of granite dust typically is discarded in landfills [4-6]. Incorporating this waste in ordinary concrete is not possible, because it increases W/C ratio, decrease durability properties (mainly resistance to salt-scaling), increases permeability, decrease strength and etc. However granite waste dust utilisation in ultra-light weight concrete is possible, because ULWC has completely different structure, it has high porosity concertation, high W/C ratio, and usually lower compressive strength in this type of concrete is expected. Utilisation of granite dust in ULWC could help reduce the amount of waste discharged in landfills.

The main goal of this research is to determine effect of waste granite dust on main properties of ultra-light weight concrete and create non-autoclaved ultra-light weight concrete.

2. Materials

Cement. Portland cement CEM I 52.5 R was used in the experiments. Main properties: paste of normal consistency – 28.5%; specific surface (by Blaine) – 4840 cm^2/kg; soundness (by Le Chatielier) – 1.0 mm; setting time (initial/final) – 110/210 min; compressive strength (after 2/28 days) – 32.3/63.1 MPa. Mineral composition: C_3S – 68.70; C_2S – 8.70; C_3A – 0.20; C_4AF – 15.90. The particle size distribution is shown in Fig. 1.

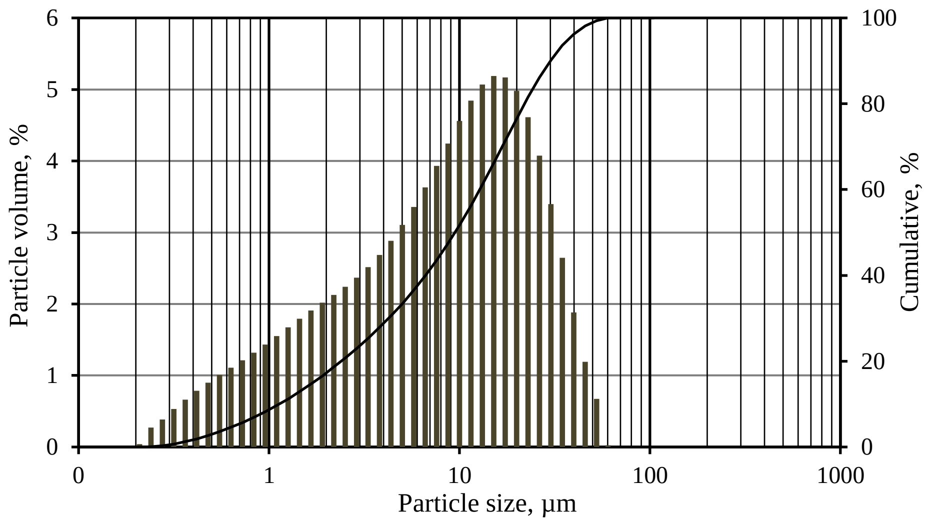

Figure1. Particle size distribution of Portland cement

Waste of granite dust. Granite dust is a by-product of crushed granite produced by JSC “Granitas“ (Lithuania). Main properties: density – 2612 kg/m^3, bulk density – 1600 kg/m^3, amount of clay impurities – 32%. In experiment waste of granite dust was additionally milled, thus specific surface area varied: 4532 cm^2/g, 5805 cm^2/g and 6822 cm^2/g, but for ultra-light weight concrete properties research was used dust with specific surface area 6822 cm^2/g.

Aluminum powder. In the research was used aluminium powder (Al) covered with paraffin and average size of particles - 30 µm.

Gypsum (β-calcium sulphate hemihydrate). The main properties of gypsum: specific surface area (by Blaine) – 5000 cm^2/g, specific density – 2318 kg/m^3, the average particle size – 34.42 µm. Chemical composition: CaO – 38.2 %, SO_3 – 50.1%, insolubles – 4.2 %, loss of ignition – 6.8 %.

Polypropylene fibers. Main properties: raw material – polypropylene; shape – rounded; diameter -16 µm; fiber length -12 mm, fiber quantity - 275 million pcs/kg; flexibility modulus - 3500-

3900 N/mm²; tensile strength - 400 N/mm²; melting temperature - 160-170ºC; flammable temperature - >320ºC; chemical material resistance - good.

3. Methods

Mix preparation. Ultra-light weight concrete was prepared by using dry aggregates. Cement, gypsum, granite dust aluminium powder, NaOH and water were dosed by weight. Cubes (100x100x100 mm) were formed for the research to determine main properties of the concrete. Composition were mixed with laboratory mixer (G-250). Homogeneous mixes were cast in moulds and kept for 24 h in laboratory environment (20±2 ºC and 60 RH). After demoulding, all samples were kept under laboratory condition (20±2 and RH 40-60 %) till age of 28 days. Samples were not kept underwater. In the experiment (Table 1), notation of created mixes: C100G0 – pure Portland cement without any substitution of granite dust, C85G15, C70G30, C55G45 – when certain percentage (15%, 30% and 45% accordingly) of Portland cement were substituted to granite dust (by mass).

Table 1. Compositions of ultra-light weight concrete

No.	Composition	Water, l	Cement, kg/m^3	Granite dust, kg/m^3	Al powder, kg/m^3	Gypsum, kg/m^3	Polypropylene fibers, kg/m^3
1	C100G0	205.5	290.8	-	0.8	1.8	0.81
2	C85G15	205.5	247.2	43.62	0.8	1.8	0.81
3	C70G30		203.6	87.62			
4	C55G45		159.9	130.9			

Specific surface and particle size distribution. The specific surface (fineness) was measured by using Blaine instrument, according to the EN 196-6:2010 standard [8]. The particle size distribution was measured with a ''Mastersize 2000'' instrument.

Density and compressive strength. The compressive strength test was performed according to EN 12390-4:2000 standard [9]. For compressive strength, there were used 3 cubes (100x100x100 mm). Density was calculated as average value mass dividing by volume from 3 cubes (100x100x100 mm).

Thermal conductivity. Thermal conductivity was calculated according to the LST EN 1745:2012 standard [10].

Water absorption. Water absorption was performed according to EN 772-11:2011 standard [11].

4. Results

4.1. Elemental analysis of granite dust

Elemental analysis of granite dust waste was performed. Main results are given in table 2 and Figure 2. As raw material granite dust in the research cannot be used, because there were a lot of conglomerations, thus additional milling was performed, and powder with specific surface areas 4532 cm^2/g (without milling), 5805 cm^2/g (10 min of milling) and 6822 cm^2/g (15 min of milling) was researched. The idea of elemental analysis was to estimate, that prolonged milling will not put additional impurities of Fe, analyse, to examine how chemical elements can effect structure of concrete, and compare with clay.

SiO_2 and Al_2O_3 are two main chemical compounds can be found in granite rock. The same compounds also could be found and in clays, the main different is, that in granite rock these compounds usually are found in crystalline form, however in chemical reaction with cement are more preferable amorphous form. If compounds SiO_2 and Al_2O_3 are in crystalline form they under normal condition they will act as inert fillers and will not affect properties of concrete in any way. Amorphous structure of SiO_2 has positive effect in reaction with hydrated lime ($Ca(OH)_2$) and low basicity C-S-H are formed, which has positive effect on mechanical and durability properties. The Al_2O_3 compound in crystalline form is mainly found in various clays. This compound has negative effect on concrete properties: increases W/C ratio, increases required amount of superplasticizer, increases shrinkage, increases water absorption, decreases resistance to salt-scaling, increases porosity. Negative effect of this compound can be eliminated by heating and changing structure from crystalline to amorphous. Founded compounds as MgO increases inhomogeneity of the mix, K_2O and Na_2O can increase pH value of pore solution, which increases possibility to appear alkali silica reaction with certain coarse aggregate. When pore solution has very high concentration of K^+ and Na^+ solubility of Ca^+ tends to decrease, thus overall amount of C-S-H will decrease. Higher amounts of FeO and Fe_2O_3 can mainly effect the colour of concrete, other compounds do not have any negative effect or it is insignificant.

Table 2. Amount of element of granite dust waste after different milling times

Element	Amount of elements after milling		
	4532 cm^2/g	5805 cm^2/g	6822 cm^2/g
O	63.10	64.62	63.82
Si	18.02	16.65	17.14
Al	7.04	6.51	7.44
Fe	2.80	2.18	2.59
K	2.35	1.80	2.25
Ca	2.02	2.09	2.11
Mg	1.91	1.75	1.75
Na	1.89	2.20	1.96
S	0.54	0.55	0.63
Ti	0.24	0.19	0.24
Mn	0.08	-	0.08
P	-	0.21	-

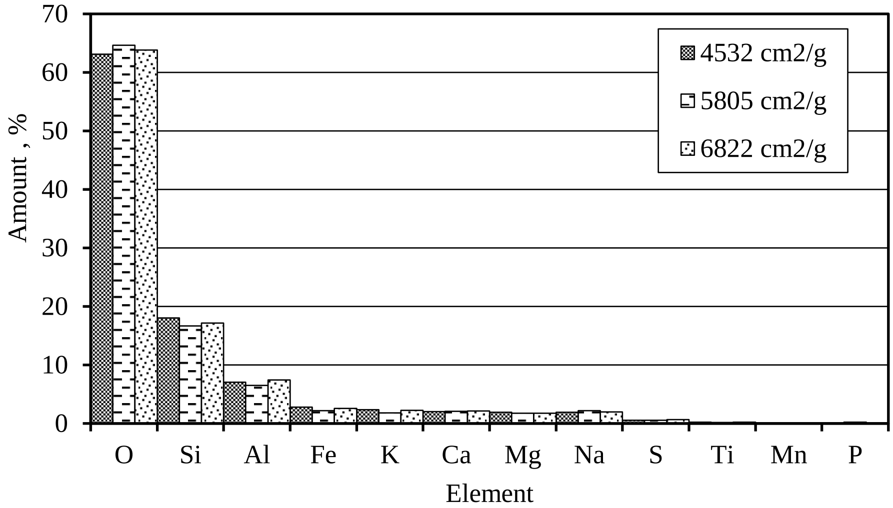

Figure 2. Elements founded in different finest of granite dust waste

4.2. SEM analysis of granite dust

SEM micrographs of granite dust can be found on Figure 3. It could be seen various forms particles with sharp angles, before milling particles size were between 10 μm and 100 μm (Fig.3-a an Fig.3-c), also were a lot of elongated particles, surfaces discontinuities, which has negative effect on proper particle size distribution, and increases amount of water for normal consistency mix. After milling particles became more spherical which have positive effect on fresh mix rheology.

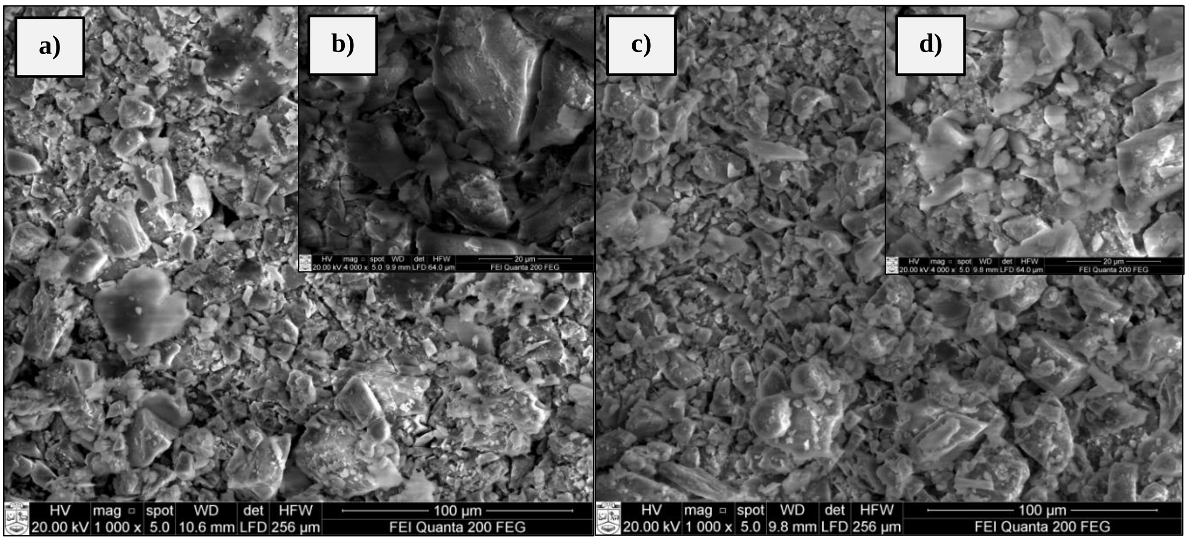

Figure 3. SEM micrograph of waste granite dust a) and b) without milling (acordingly x1000 and x4000 magnification); c) and d) after milling (acordingly x1000 and x4000 magnification)

4.3. Density and compressive strength

Main results of density and compressive strength could be found on Table 3 and Fig. 4. It was noticed, that when Portland cement was substituted to granite dust from 0 % up to 45 % (by mass), density decreased about 15 % from 697 kg/m^3 (C100G0) down to 595 kg/m^3 (C55G45), however compressive strength decreased about 50 % times, from 3,33 MPa (C100G0) down to 1,66 MPa (C55G45). In order to build one storage individual houses, minimum compressive strength of blocks, should not be less than 3 MPa. According to the results could be stated, that 15 % substation of cement to granite dust is the maximum amount possible, to keep specification.

Table 3. Properties of ultra-light weight concrete

Composition	Density, kg/m^3	Compressive strength, MPa	Water absorption after 48 h.	Thermal conductivity, W/m·K
C100G0	697	3.33	42	0.1794
C85G15	677	3.08	44	0.1754
C70G30	629	2.13	46	0.1658
C55G45	595	1.66	53	0.1585

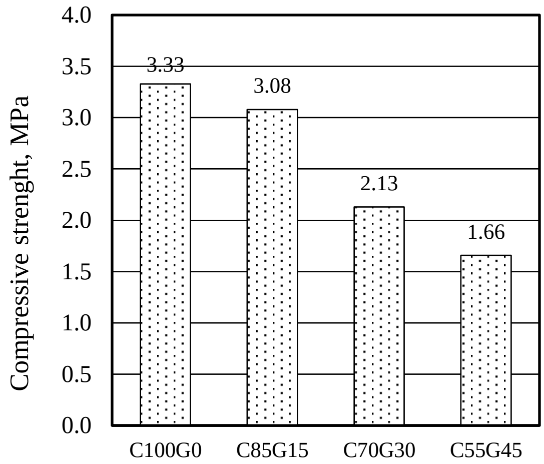

Figure 4. Relationship between amount of granite dust waste and compressive strength

4.4. Water absorption, thermal conductivity and microstructure

Water absorption and thermal conductivity testing/calculations results could be found on Table 3. The highest water absorption was observed in mixture (C55G45), where 45 % of Portland cement was substituted to waste of granite dust. Water absorption varied from 42 % (C100G0) up to 53 % (C55G45). Increase of water absorption probably related more due to decreased density than due to utilized higher amount of granite dust waste. Theoretically calculated thermal conductivity coefficient varied from 0.1794 (W/m·K) up to 0.1585 (W/m·K). Value of thermal conductivity is very similar to autoclave aerate concrete, from which most ultra-light weight concrete blocks are made. Microstructure of created ULWC sampled could be found on Figure 5. It could be observed, that there is no significant difference in air pore structure, between reference mixture (C100G0) (Figure 5-a) without waste of granite dust, and comparing with composition (C85G15), where 15 % of Portland cement was substituted to granite dust (Figure 5-b).

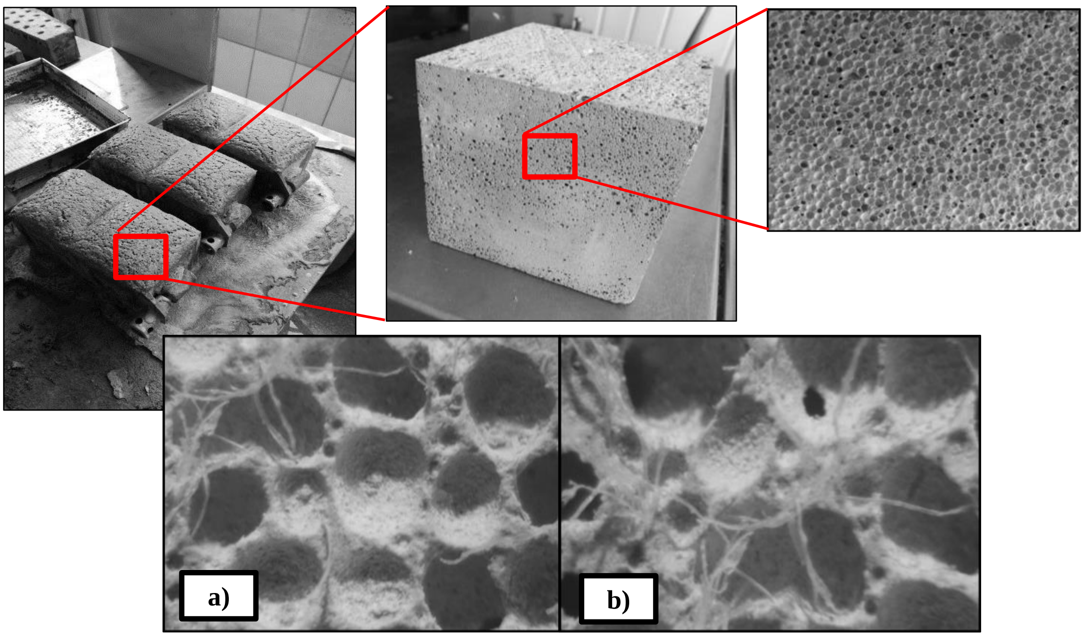

Figure 5. Structure of ultra-light weight concrete: a) without waste of granite dust and b) with waste of granite dust (replaced 15 % by mass of Portland cement to granite dust), when magnification x80

5. Conclusions

1. Waste of granite dust does not have any negative impact on micro and macro structure of ultra-light weight concrete.
2. Waste of granite dust can be properly utilized in ultra-light weight concrete without significant compressive strength loss.
3. Ultra-light weight concrete with density of 677 kg/m3, compressive strength of 3.08 MPa and thermal conductivity of 0.1754 W/m·K can be created when 15 % of Portland cement is substituted to waste of granite dust.

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