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Production Waste of Granite Rubble Utilisation in Ultra High Performance Concrete

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Production waste of granite rubble is a serious problem for many manufacturers. Year after year quantity of granite waste is growing, but manufacturers are still unlucky to find new ways where properly utilize this waste. The main problem is, that waste of granite has high quantity of impurities and its specific surface is greater, than cement, all particles have angular surface and impurities, so all mixes containing waste of granite will require more quantity of water for similar viscosity mix, will require more cement to meet required properties and probably will have worse granular curve of concrete mix. One area where waste of granite could be utilized is in ultra high performance concrete (UHPC). UHPC could be a good alternative for utilization of waste of granite rubble. In this article researched, how waste of granite rubble is affecting main properties of UHPC: viscosity, density and compressive strength. Waste of granite rubble can be used as micro filler or could replace some quantity of cement. If research confirms mentioned assumption, waste of granite rubble could not only be utilized in the future but also price of UHPC could be lowered.

Keywords: *granite rubble waste, ultra high performance concrete(UHPC).*

1. Introduction

Concrete has been a leading construction material for over a century. While during the last two decades Ultra High Performance concrete (UHPC) has been developed steadily (Nguyen Van Tuan et al. 2010) The compressive strength of UHPC has been proved to be over 100 MPa, water and cement ratio is usually $W/C \leq 0{,}25$. Absence of coarse aggregates is a key aspect for the perfect microstructure, higher compressive strength and durability properties. It is more durable because of low water-to-cementitious materials ratio results in very low porosity (Arunachalam K et al. 2011). Due to the fact that cement is made of not renewable resources, scientists are trying to find solution how to reach the same (or even better) mechanical properties and lower price using less content of cement and other expensive fine aggregates. Some by-products or waste materials such as marble, granite, fly ash, granulated blast furnace slag, silica fume could be incorporated in UHPC (Nguyen Van Tuan et al. 2010, Nima Farzadnia1 et al. 2011, Nuno Almeida et al. 2007). Aggregates may introduce some variability to concrete production according to their chemical and petrographical structures (Demir L., 2009). One of the way is granite rubble waste, which is cheap and widespread available, because granite cutting industry produces large amounts of sludge every day (I. Mármol et al. 2010, T. Felixkala and P. Partheeban, 2010). Leaving the waste materials to the nature directly can cause serious environmental problems while nowadays the sustainability of the material is a very critical criterion (H. Hebhoub et al. 2011). "Sustainable construction" is expected to provide for a minimum impact on the environment, maximizes structural performance and provides a minimum total life-cycle cost solution (Yen Lei Vooa and Stephen J. Foster, 2010, Hanifi Binici et al. 2008). There are few studies which show that granite rubble waste has a high potential as a raw material for the ceramic industry (I. Mármol et al. 2010, Vieira CMF et al. 2004, Torres P at al. 2007). What is more, some other researches were made to probe and assess the mechanical properties of concrete made with waste aggregates. Žymantas Rudžionis et al. (2005) investigated that granite fines are effective only 2.5…5% from cement mass in self-compacting concrete: the bulk density slightly increases, slump flow rapidly decreases (except it remains the same when 2.5% of cement is replaced) and increases compressive strength. Other researchers S. A. Abukersh and C. A. Fairfield (2011) determined that as the red granite dust content increased, the slump initially increased, while beyond 20% cement replacement, the slump decreased to reach a minimum at 30% red granite dust content. It is difficult to make comparisons between concrete results because the few existing studies do not always have the same concerns and results. This paper includes two main points of the view. First of all, how does the usage of different size of granite rubble waste particles affect its main characteristics (dynamic viscosity, density and compressive strength). Secondly, to determine properties of UHPC with cement replacement with granite dust at levels 5%, 10%, 15%, 20% as part of its standard manufacturing process and properties of UHPC with used granite rubble waste as a micro filler.

2. Materials used in experiment

Cement. Lithuanian company AB "Akmenės cementas" Portland cement CEM I 52.5 R was used in the experiments. Its properties are shown in tables 1 and 2, granulometric curve is shown in the Fig. 1. Properties are determined in accordance with LST EN 197-1 standard.

Concrete micro fillers

SiO_2 fume. „*BASF*" company SiO_2 fume were used in the experiments. It is ferro-silicon alloys result making very fine dust (with a large amount of amorphous SiO_2). Key properties: density – 2120 kg/m^3, bulk density (freely poured/compacted) – 255/329 kg/m^3, the specific surface area – 3524 m^2/kg, hygroscopicity – 158%, natural flowing angle – 54º. Chemical composition: SiO_2 (92,08%), Al_2O_3 (1,16%), Fe_2O_3 (1,24%), CaO (1,07%), MgO (0,80%), SO_3 (1,27%), K_2O (0,67%), Na_2O (1,13%). Granulometric curve is shown in the Fig. 2. Properties meet LST EN 12620 standard.

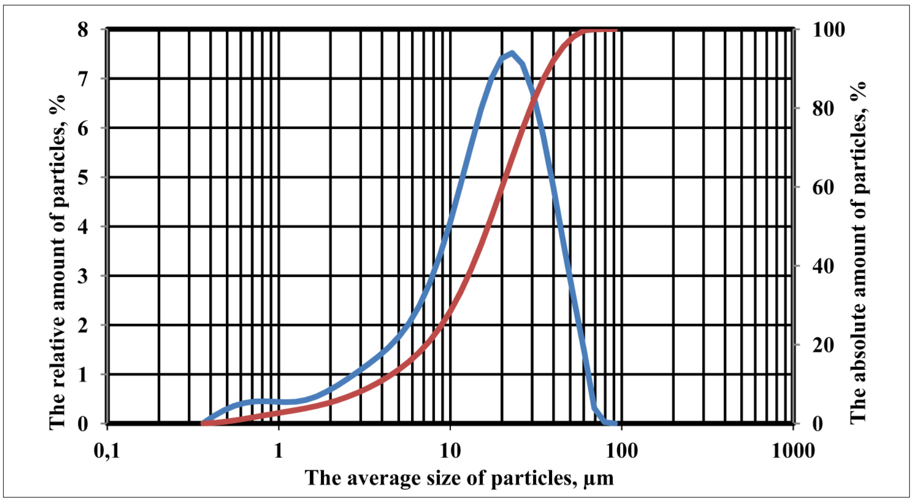

Fig. 1. AB „Akmenės cementas" cement 52.5 R granulometric curve

Table 1. Portland cement CEM I 52.5 R used in experiments physical-mechanical properties

Used Portland cement	Normal paste consistency, %	Constancy of volume , mm	Setting time, min.	Specific surface area, m^2/kg	Compressive strength, MPa (after 2/28)
AB "Akmenės cementas"	29,3	1,0	145	-	38,6/65,3

Table 2. Portland cement CEM I 52.5 R used in experiment composition of chemical compounds

Chemical compounds, %	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Cl^-	MgO	CaO_{free}
AB "Akmenės cementas"	20,61	5,45	3,36	63,42	0,80	0,00	3,84	0,73

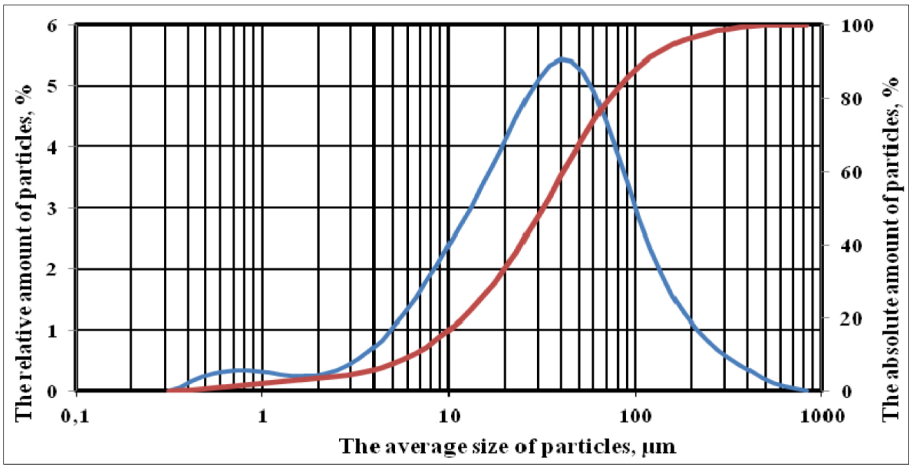

Fig. 2. SiO_2 fume dust granulometric curve

Granite rubble waste. Company UAB „Granitas“ granite rubble raw waste (S0) and ground granite rubble waste (S2) were used in the experiments (table 3). Key properties: density – 2612 kg/m^3, bulk density – 1600 kg/m^3, clay and dust content – 32 %. Granite rubble waste was scanned with electron microscope. (Fig. 3).

***Table 3.** Particle size and specific surface area dependence on grinding time*

Marking	S_0	S_1	S_2	S_3	S_4
Grinding time, min	0	5	10	15	20
Specific surface area S, cm^2/g	4532	5805	6822	6989	7272
The average particle size, µm	70,63	–	50,43	–	–

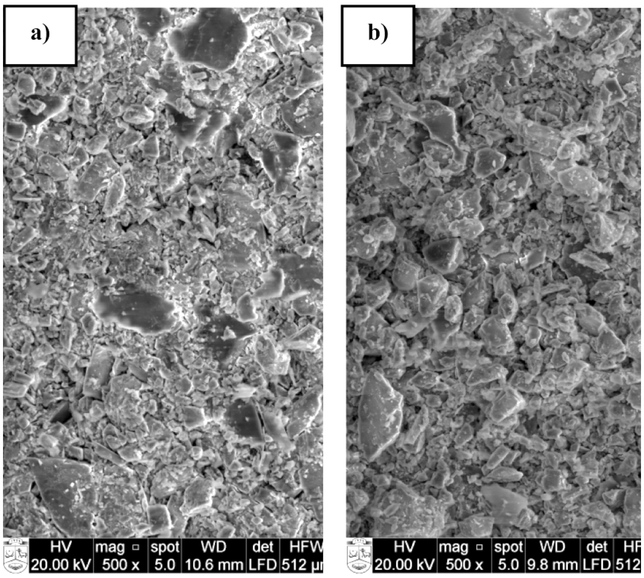

***Fig. 3.** Granite rubble waste scanned with electron microscope: a) Before grinding; b) After 10 minutes of grinding*

Ground quartz sand. Company AB „*Anykščių kvarcas*“ ground quartz sand was used in the experiments. Its – density – 2670 kg/m^3, bulk density – 1425 kg/m^3, clay and dust content – 0,5 %. Granulometric curve is shown in the Fig. 4. Properties of filler meet LST EN 12620 standard.

Concrete fillers

Quartz sand. Quarry of „Anykščių kvarcas“ sand of 0/2 fraction was used in the experiments. Its density– 2670 kg/m^3, bulk density – 1600 kg/m^3, clay and dust content – 0,5 %. Properties of filler meet LST EN 12620 standard.

Chemical additives

Superplasticizer „*Glenium SKY 623*“ based on polycarboxylate ether- produced by company „BASF“ was used in the experiments. Its specifications are: the active substance – polycarboxylate ether, appearance – pale brown cloudy liquid, density – 1.010÷1.070 g/cm^3, maximum content of chloride (percent by weight) – 0.10 %, maximum equivalent content of alkali (percent by weight) – 2.5 %, storage – 5÷20 °C.

3. Methods

Concrete mixture preparation. Dry fillers were used to prepare concrete mixtures. Cement, fillers and micro fillers were dosed by mass, while water and chemical additives – by volume (table 4). Some chemical additives were dissolved in water and mixed into the mixture together with water, some without water.

The mixing of concrete mixes was performed by the vibro-mixer (Fig. 5), due to its unique design and enhanced vibration, vibrating stirrer, comparing with other mixers, is more suitable to prepare a homogenous, high viscosity concrete mixture with the lowest possible water and cement ratio. The main parameters of vibrating stirrer: oscillation frequency 30–500 Hz, volume 4 liters. Mixing starts from the lowest frequency and during 15 seconds it is raised to the maximum. Mixing procedure is shown in table 5.

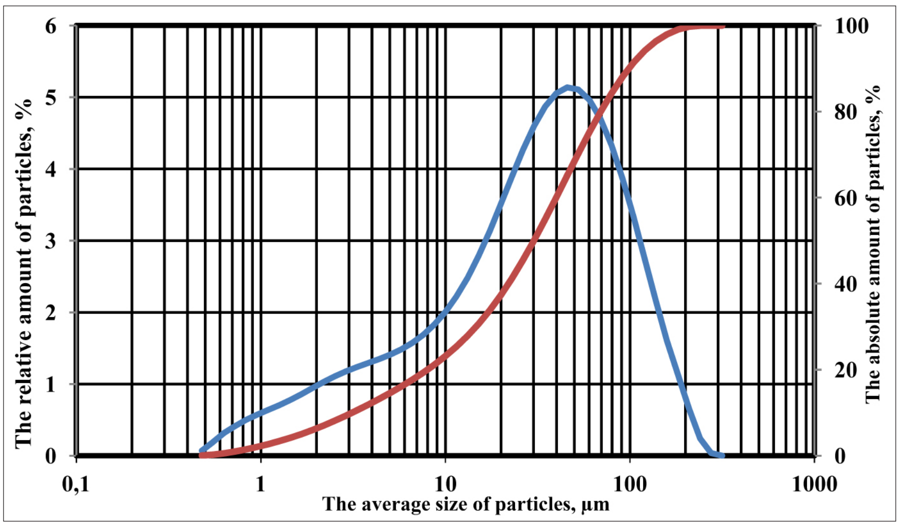

***Fig. 4.** Ground quartz sand granulometric curve*

Table 4. Composition of concrete mix, 1 m³

Specimen number	W, l	C, kg	W/C	Micro fillers, kg			Fillers, kg	Chemical additives, l
				SiO_2	$S_{g.quartz.,}$	G	Fr 0/2	G623
1	170	735	0,23	99	412	-	962	36,76
2	170	735	0,23	99	-	$412^{(S_0)}$	962	36,76
3	170	735	0,23	99	-	$412^{(S_2)}$	962	36,76
4	170	698	0,24	99	412	37(S2)	962	36,76
5	170	662	0,26	99	412	74(S2)	962	36,76
6	170	625	0,27	99	412	110(S2)	962	36,76
7	170	588	0,29	99	412	735(S2)	962	36,76

Note: W – Water; C –Cement; W/C – Water and cement ratio; SiO_2 – SiO_2 fume; $S_{g.quartz.,}$ – ground quartz sand; G – ground granite rubble waste; Fr 0/2 – 0/2 fraction quartz sand; G623 – Superplastizer Glenium ACE 623. S_0 ir S_2 different fineness granite rubble waste (table 3).

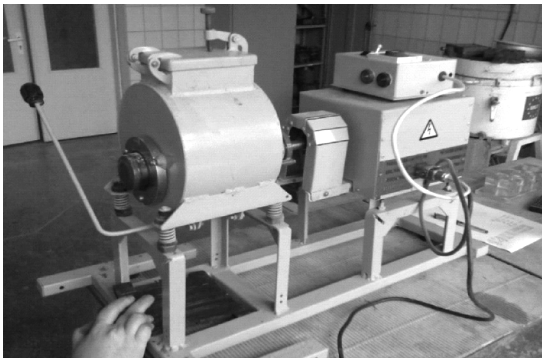

Fig. 5. *Laboratory vibro-mixer*

Table 5. *UHPC mixing procedure*

Time, s	Mixing procedure
60	Sand, SiO_2 micro dust, granite and cement homogenization
30	All necessary water is poured and 50 % of superplastizer
60	Homogenization
120	Pause
30	Dosage of the rest superplastizer
60	Homogenization

Mixing procedure of UHPC is slightly different from the conventional concrete, and mixing process usually lasts longer. Due to very low W/C ratio mixture has significantly higher viscosity and shear stresses. The most ideal UHPC mixers are those who have a very intensive mixing capability and which has a possibility to make a vacuum during the mixing process. In practice, however, these mixers are expensive and not every company or a laboratory is able to buy one.

Dynamic viscosity. Ultra High Performance concrete due to its low W/C ratio is a very viscous mixture, however differently than conventional concrete, due to perfect selected components, it has a very high slump, sometimes close to self-compacting concrete. Due to relatively high UHPC mix shear stresses rheological properties of mix are more convenient to assess measuring dynamic viscosity, rather than slump. Dynamic viscosity of the mixture can be measured using Falling ball method (Chiara F. Ferraris, 1999). The biggest advantage of this method is that there is no need for large amount of the mix and relatively quick results are obtained. The biggest drawback of this method is that viscosity cannot be determined if the mix includes certain eddy current. That means that concrete mix, which is explored, cannot be influenced by any external impact, it must be in a natural state (i.e., during the measurement mix cannot be vibrated).

Fig. 6. *Dynamic viscosity detection equipment*

Dynamic viscosity of concrete mixes was determined before forming concrete specimens. Modified Stokes law was applied, using 10.0 cm high and 4.7 cm diameter plastic tube, which was filled with known density concrete mix (Fig. 6). Constant sinking velocity time of steel ball was measured. Ball position in a cylindrical tube was recorded by metal detector. Steel ball before measurement was wetted. Viscosity is calculated using 1 formula.

$$\eta = \frac{2 \cdot g \cdot r^2 \cdot (\rho_{rut} - \rho_{sk})}{9 \cdot v_{past}} \cdot \frac{1}{1 + \frac{2,4 \cdot r}{R}}; \quad (1)$$

where: g – acceleration of free fall [m/s^2]; r – steel ball radius [m]; ρ_{rut} – steel ball density [kg/m^3]; ρ_{sk} – concrete mixture density [kg/m^3]; R – plastic cylinder radius [m]; v_{past} – constant steel ball sinking velocity [m/s], calculated by 2 formula.

$$v_{past} = \frac{l}{t}; \qquad (2)$$

where: l – constant steel ball sinking path [m], during the time t [s].

Forming and hardening. There were formed 6 non-conventional form cylindrical specimens (diameter d = 50 mm and height h = 50 mm) to define properties of hardened concrete. Concrete mix was poured freely into molds, without compaction or vibration. Afterwards molds were covered with damp cloth and left to harden for 1 day in laboratory conditions (20±2 ºC). After 1 day, specimens were demoulded and left to harden in water (20±2 ºC) for 28 days.

4. Results

There were made 7 different – Ultra High Performance concrete mixes based on the methods described above. Specimen 1 (table 4) is reference mix and was made without granite rubble waste. Specimens 2 and 3 (table 4) were made only with granite rubble waste (not using quartz sand) with the same contents of aggregates but had different specific surface of granite particles. Granite rubble waste was ground for 5, 10, 15 and 20 minutes in laboratory vibro-mixer (Fig. 5) before the concrete mixing in order to determine the changes in particle fineness of granite. The study shows that effective grinding time is 10 minutes, after that time specific particle surface varies slightly (Fig. 7). Thus continuing grinding only increases the grinding power consumption, instead of that it would have access to more detailed micro-filler. Therefore, only two different particles sizes were used in further experiments (S_0, S_2).

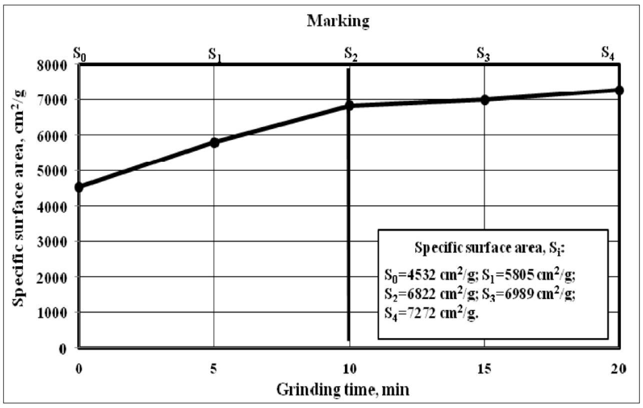

Fig. 7. Granite rubble waste fineness dependence on grinding time

During the experiment three main characteristics (dynamic viscosity, density and compressive strength) were determined and compared with reference mix. Granite rubble waste instead of the quartz sand in the specimens 2 and 3 (S_0 = 4532 cm^2/g and S_2 = 6822 cm^2/g, respectively) was used. Test shows that dynamic viscosity increases when an admixture is coarse, while using finer aggregate causes this property to reduce (Fig. 8). This is due to the fact that higher specific surface area causes higher friction between particles which means increased dynamic viscosity. What is more, finer particles require more water content and there is high content of aggregates.

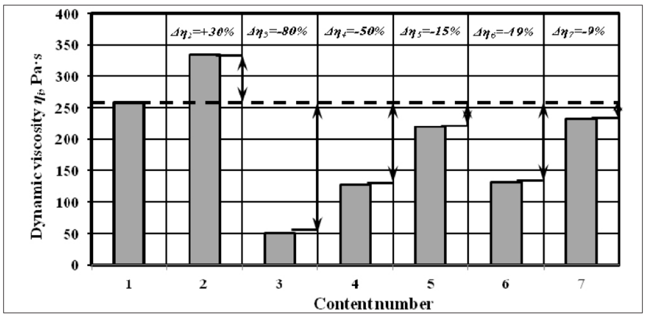

Fig. 8. UHPC mix dynamic viscosity using different content of granite rubble waste

Table 6. Physical- mechanical properties of different composition of UHPC

Specimen number	Dynamic viscosity, η (Pa·s)	$\Delta\eta$, %	Density, ρ (kg/m^3)	$\Delta\rho$, %	Compressive strength, f (MPa)	Δf, %
1	257	0	2433	0,00	140	0
$2^{(S0)}$	335	30	2421	-0,52	128	-8,71
$3^{(S2)}$	51	-80	2335	-4,04	95	-32,04
$4^{(S2,5\%)}$	128	-50	2411	-0,91	125	-10,45
$5^{(S2,10\%)}$	219	-15	2379	-2,21	131	-6,30
$6^{(S2,15\%)}$	132	-49	2386	-1,95	127	-9,04
$7^{(S2,20\%)}$	233	-9	2377	-2,31	128	-8,59

Note: dynamic viscosity ($\Delta\eta$), density ($\Delta\rho$) and compressive strength (Δf) changes comparing with control mixture; „-„ symbol shows the percentage decrease of certain property comparing it with reference.

During the experiment it is observed that density generally is decreased replacing different part of the cement with granite rubble waste (Fig. 9). The reduction was negligible and maximum value was only 2.31% (replacing 20% of cement with granite rubble waste), while in the third specimen (quartz sand was fully replaced by granite dust) the density reduced more than 4%. Concrete density decreased due to the fact that higher quantity of water was used, therefore porosity increased. Water demand increased also due to the finer aggregates and clay impurities.

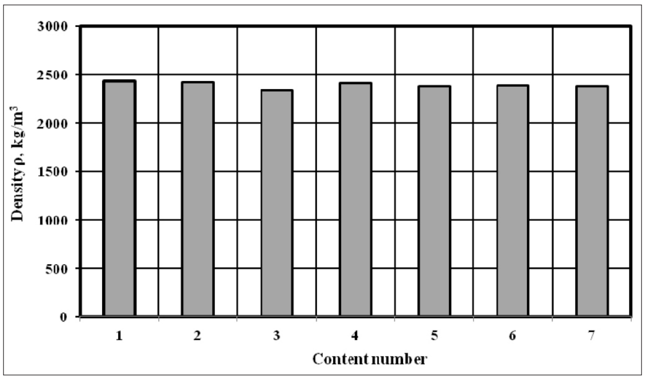

Fig. 9. *UHPC mix density using different content of granite rubble*

Specimens 3-7 were made with granite rubble waste as a partial cement replacement. Granite rubble waste used in these mixtures had the same specific surface area S_2 = 6822 cm^2/g and might be considered as micro filler. Using more percentage of granite instead of cement tends to increase water and cement ratio. Table 6 displays mixes used for the selection of the best granite rubble waste cement replacement level and their resulting workability. The mix with up to 10% of cement replaced with granite rubble waste content reached a maximum compressive strength of 131 MPa, (below the 140 MPa mean strength of the control mixture. Using higher percentage of granite rubble waste (higher than 10%) compressive strength tends to decrease slightly (until 128 MPa when 10% as cement replacement) (Fig. 10).

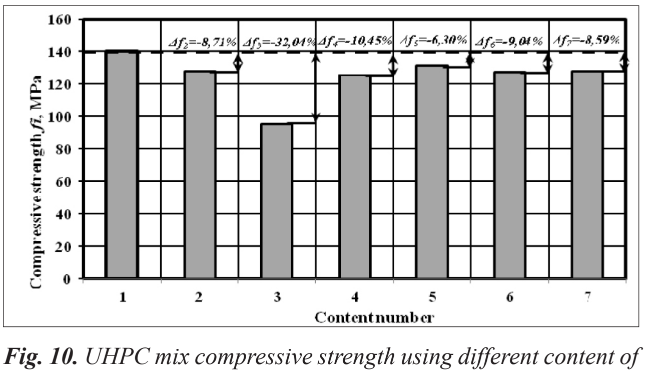

Fig. 10. *UHPC mix compressive strength using different content of granite rubble at the age of 28 days*

5. Conclusions

1. The study shows that the most effective grinding time is 10 minutes (S_2=6822 cm^2/g), after that time specific surface varies slightly and further grinding due to economic reasons is not effective.

2. Replacing quartz sand with granite rubble waste (S_0 = 4532 cm^2/g) shows that compressive strength and density tend to decrease 8,71% and 0,52%, respectively, while dynamic viscosity tends to increase by 30% comparing with reference mix.

3. Using granite rubble waste as a partial cement replacement, compressive strength of the mixes decreased from 6,3% (using 10% of granite rubble), till 10,45% (using 5% of granite rubble waste); dynamic mixture viscosity decreased from 9% (when 20% cement is replaced by granite rubble waste), till 50% (when replaced 5% of cement); density decreased slightly (maximum 2,31%) in all mixes.

4. Although granite rubble waste can be used in UHPC, due to deterioration of the properties and the economic reasons, there is no significant effect observed.

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