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Interactions among the characteristics of concretes containing a high portion of micro-filler

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Utilization of the construction and demolition waste (C&DW) for the production of building materials is discussed for a longer time worldwide, whether in the form of coarse aggregates or in the fine-grain form as a micro-filler/additive. The valorization of waste/by-products in the production of building materials can be improved by their modification using some treatment technologies.

The article presents the results of testing the concretes containing a high dosage of the C&DW that were previously adjusted into fine-particle powders. Those powders were prepared by the grinding and sorting of concrete, brick and glass to specific dimensions – under 250 μm. They were intended as a micro filler substitution of natural aggregate (NA) within the 0/4 fraction to the extent permitted by technological rules. Except for environmental reasons (saving the natural sources of NA), the high dosage of micro-fillers was intended for improving the technical parameters of concrete. The main goal was to attain a concrete of high fluidity, as it is in great demand by constructors. That is why also other parameters of concrete mixtures were optimized; the amount of water as well as the dosage of plasticizer were adjusted during mixing in order to keep the standard criteria.

Next, a positive impact on the properties of hardened concrete was expected due to the effect of micro-fillers in the concrete microstructure. The results of these properties are presented and discussed in the paper, namely density, compressive strength, water absorption capacity and frost resistance. The analysis of the results is focused on the effect of an individual powdered material, on the interaction of the resulting properties of concretes, as well as on the changes of those properties in time, since the data were collected at 7, 28 and 365 days of hardening. Positive effect of fine-grain form of brick, glass and concrete on the compressive strength and partially on the frost resistance was found compared to the reference concrete, while it is not the case of water absorption capacity.

Key words: fine grain C&DW, micro-filler, concrete of high fluidity, density, compressive strength

Introduction

At present, new types of concrete products have been introduced in building industry, such as pumping concrete, self-compacting concrete (SCC), high-performance concrete (HPC), high strength concrete (HSC), and ultra-high performance concrete (UHPC). These are complex multi-component mix systems [1]. Concretes of high workability are today requested by constructors because of some advantages, mainly the easier on-site placing and the better quality of the concrete structure. Nevertheless, self-compacting concrete is not widely used as it needs high quality control for the concrete production, transporting and casting to ensure the self-compacting property and a high resistance to aggregate segregation. Instead, high-workable concretes are preferred now. They are defined by the flow classes F5–F6 (560–750 mm). However, flowing concrete mixtures of standard composition run the risk of:

- bleeding, settlement, and segregation;
- a weak interfacial transition zone between the cement paste and the aggregate, as well as between the cement paste and the reinforcing steel.

This is why high workability is related not only with the high consistency, but also with the high cohesiveness of the mixture. The stability or resistance to segregation of the plastic concrete mixture is attained by increasing the total quantity of fines in the concrete and/or by using admixtures to modify the viscosity of the mixture. An increased content of fines may be achieved by increasing the content of cementitious materials or by incorporating mineral fines. Special requirements for aggregate grading are to be taken into account, and especially the content of fine particles (so called “micro filler”) should be controlled [1]. Compared to conventional concrete which typically contains about 45 % of the coarse aggregate and 25 % of the fine aggregate (by absolute volume), fluid concrete mixtures are composed of approximately 25 to 30 % of a coarse aggregate, 30–35 % of a fine aggregate, and about 10 % of extra-fine particles (exclusive of cement). Micro fillers improve the mix workability and provide for particle dense packing in a hydrated cement paste. High fluidity with a relatively low water content is achieved by using superplasticizing and air-entraining admixtures.

The concrete and cement micro-fillers are materials of different fineness, such as wastes of industrial production or pulverized rocks. According to their influence on the cement hardening process, they may be classified into inert micro-fillers or chemically active ones. The chemically active micro-fillers, such as silica fume, fly ashes and others, have more than 50 % of amorphous SiO_2 which takes part in the cement hardening process. Inert micro-fillers, such as granite, dolomite, sand dust and others, in most cases have no influence on the cement hydration [2].

The construction and demolition waste, such as glass, brick and concrete dust, seems to be valuable a source of mineral fines [1, 3, 4]. Moreover, they are presented as having the pozzolanic activity if a sufficiently small particle size is obtained [5, 6]. A lot of studies present the generally positive influence of powder additives on the properties of cement mixtures [7–9].

The workability of concrete with micro-filler mineral admixtures greatly depends on the particle size, specific surface area, particle shape, and replacement level. A higher content of fines is recommended for easily workable concretes, at the time the upper limit is given to prevent the risk of a negative impact on the properties of hardened concrete (mainly shrinkage). For concretes with D_{max} = 8 mm, the quantity of particles under 250 μm is limited to the value of 600 kg per 1 m^3 of ready concrete [10].

This article is aimed to the utilization of fine-grain construction and demolition waste (C&DW – bricks, glass, and concrete) for the production of concrete mixes of higher fluidity. C&DW were modified by crushing, followed by the sorting of particles under 250 μm. For saving as much of the natural aggregate as possible, the dosage of micro-fillers was kept at the highest possible level. The interaction of the resulting properties of concretes, as well as changes of these properties in time are discussed in the paper. The analysis of the results is focused on the effect of individual powdered materials, while the data were collected at 7, 28 and 365 days of concrete curing.

Materials and methods

Three kinds of micro-fillers from C&DW were prepared by crushing in a laboratory jaw crusher, following by the separation of portions under 250 μm: building ceramics / brick powder, concrete powder, and glass powder. These materials were considered as a micro-filler a substitute of a natural aggregate (NA) in the 0/4 fraction. Their chemical composition is given in Table 1. To keep the maximum possible amount of fines, the calculation of a concrete mixture took into account the specific gravity of individual components of concrete, as well as their granularity. The granularity of both the cement and the 0/4 NA was tested before designing the mixtures to find the portion of particles under 250 μm; 45 % of particles under 250 μm for cement and 8 % for the 0/4 fraction of NA were found. By including these data into the calculation of a concrete mixture, the maximum possible amount of micro-fillers was determined. With the help of the above substitution, the basic aim of the experiment was to achieve the concrete of high fluidity (of the F5–F6 flow class, i.e. 560–750 mm according to [11]) together with keeping a specific level of the water/cement ratio (max. 0.6). This limit of the water/cement ratio was chosen with respect to recommendations for exposure classes as defined in the National Annex of EN 206 [11]. The amount of water as well as the dosage of chemical admixtures were adjusted during mixing to obtain these parameters, and they are given and discussed in [12]. The composition of concrete mixtures for this experiment is shown in Table 2.

For the complex testing of these mixtures, samples of appropriate shapes and dimensions were prepared and cured under standard conditions. A set of the properties was tested, including density, compressive strength, water absorption capacity and frost resistance, all of them under European standards. The tests were performed at 7, 28 and 365 days of curing.

Table 1. Chemical composition of tested C&DW

Materials	CaO, %	Al_2O_3, %	SiO_2, %	Fe_2O_3, %	MgO, %	Na_2O, %
Concrete powder	28.4	6.4	53.9	2.8	4.5	ND*
Brick powder	1.6	15.4	73.0	4.3	2.1	ND*
Glass powder	5.2	0.9	69.5	0.1	4.2	8.7

* ND – not detected.

Table 2. Dry components of concretes for 1 m^3 of ready mix concrete

Components	Units	Mixtures			
		Control mixture CM	Mixture with brick powder M-B	Mixture with concrete powder M-C	Mixture with glass powder M-G
Cement II/B-S 32.5 R	kg	370	370	370	370
Natural aggregate 4/8	kg	694	694	694	694
Natural aggregate 0/4	kg	1 086	652	652	652
Micro-fillers (brick, concrete and glass powders)	kg	-	346	346	346

Results and discussion

- **Density**

The density values of all hardened concretes fall into the range 2100–2390 kg/m^3; they can be classified as a normal weight concrete in accordance with [11]. The samples containing micro-fillers have a significantly higher density comparing with the control one, while the highest value of density has a mixture with the concrete powder. All samples show the tendency of increasing density in time. The density values of concrete samples are given in Fig. 1.

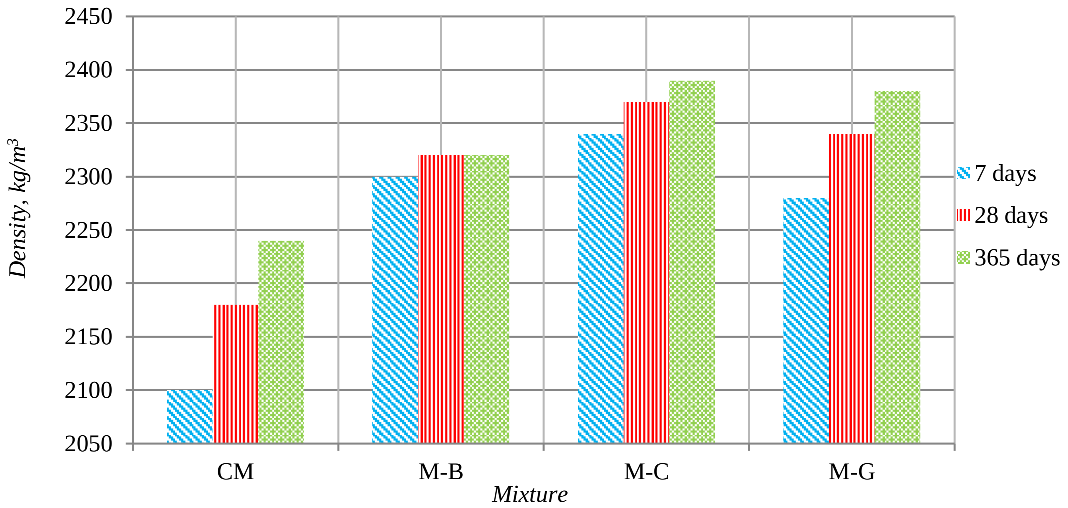

Fig. 1. Density of concrete samples containing fine grain C&DW after 7, 28 and 365 days of curing

- **Compressive strength**

The compressive strength values of all hardened concretes in 28 days fall into the range of 29–50 MPa; they can be classified as strength classes C 20/25 (CM), C 25/30 (M-G) and C 35/45 (M-B and M-C) in accordance with [11]. The samples containing micro-fillers have a higher strength comparing with the control one, and the difference increases with time. All samples show the tendency of an increasing compressive strength in time, except CM. Results of the compressive strength testing of concretes containing fine grain C&DW are shown in Fig. 2.

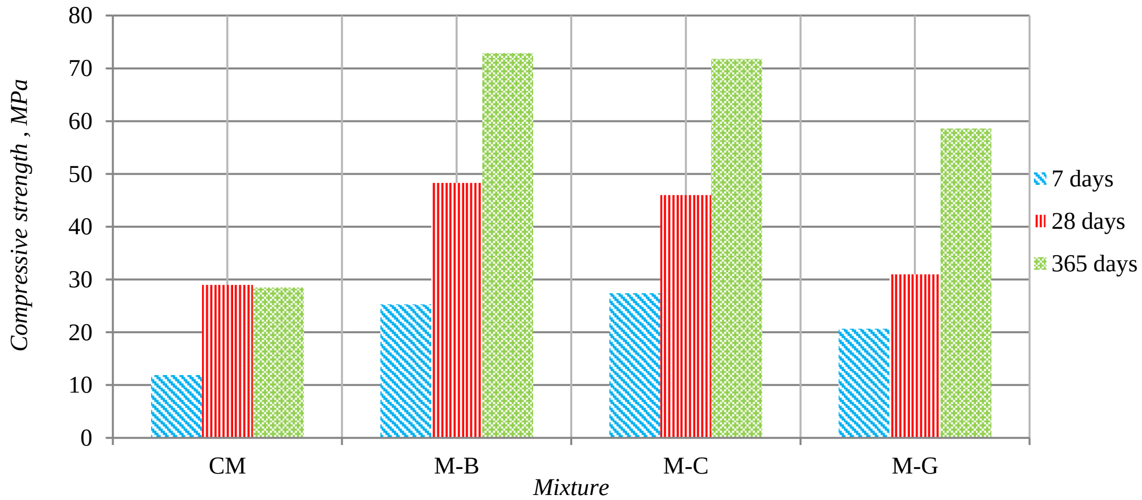

Fig. 2. Compressive strength of concrete samples containing C&DW after 7, 28 and 365 days of curing

- **Water absorption capacity**

It was measured after 24 hours of immersion in water. This parameter does not show a regular tendency in time for all mixtures. As for CM and M-G, the water absorption increases in time, while for M-B and M-C it is the opposite case.

The absorption capacity values of CM are standard if compared with conventional concretes. The samples containing micro-fillers have a higher absorption capacity than that of the control one, except M-C after 365 days. The highest absorption capacity has the mixture containing the brick powder M-B. Results of water absorption capacity testing are shown in Fig. 3.

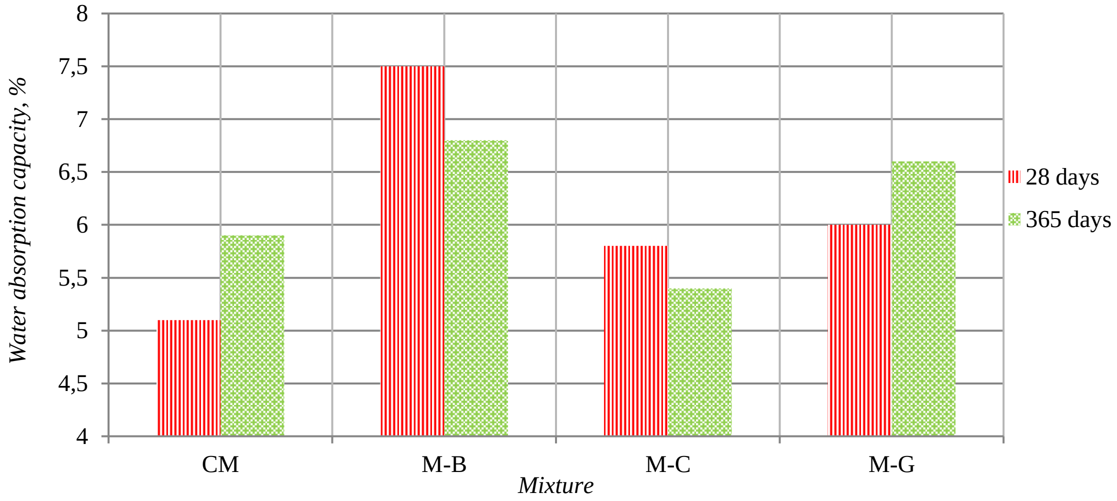

Fig. 3. Water absorption capacity of concrete samples containing fine grain C&DW after 28 and 365 days of curing

- **Frost resistance**

Frost resistance was checked by the cube test [13] in which 25 freezing–thawing cycles were applied. It is expressed as the frost resistance coefficient – the percentage of compressive strength before freezing. As is seen in the chart, samples tested after 28 days of curing have the index at 70 %, except M-G, where it is 110 %. This means a higher strength after freezing than before it. The frost resistance of CM and M-C samples is better after 365 days of curing, while it turned to be worse in the M-B case. The M-G sample was not tested after 365 days. Results of the frost resistance tests of concrete samples are shown in Fig. 4.

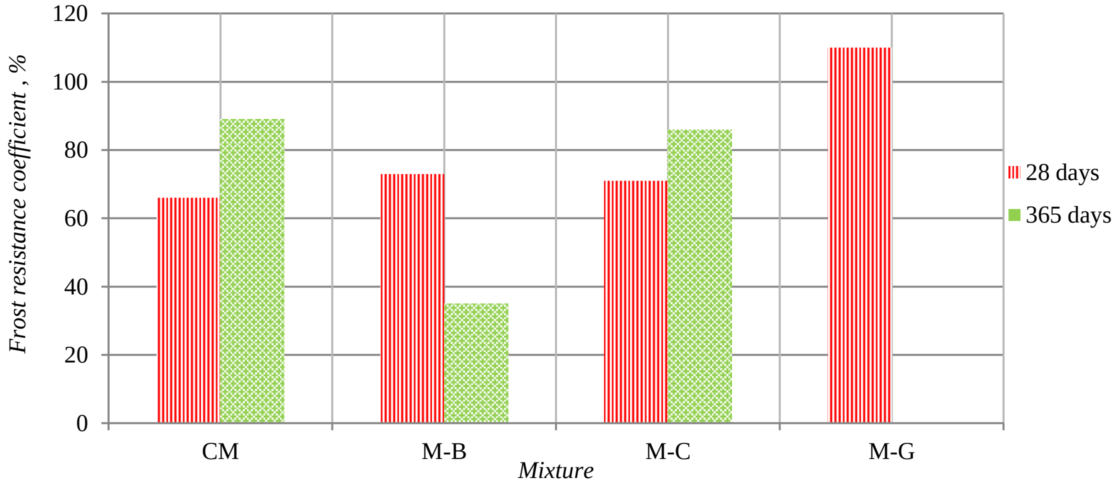

Fig. 4. The frost-resistance coefficient of concrete samples containing fine grain C&DW after 28 and 365 days of curing

Based on the results of the experiment, several interactions among the properties of concrete containing a high proportion of micro-fillers can be observed.

As is shown in Fig. 1 and Fig. 2, both density and compressive strength have an increasing tendency in the time. A direct relationship between the density and compressive strength of concretes containing a high dosage of micro-fillers can be observed, as is usual for standard concretes. As the microstructure of a concrete becomes denser, it provides a higher compressive strength. This is caused by ongoing hydration reactions in a long time period. A correlation between compressive strength and density in all curing times (7, 28 and 365 days) were expressed for each of the tested mixtures (Fig. 5), and it was found to be very tight. Figure 5 also shows how different is the position of the control mixture as compared with mixtures containing micro-fillers.

Figure 6 shows the correlations of density and compressive strength in the samples MB, MC and MG, expressed for each curing time. A different behaviour of concrete samples depending on the kind of micro-filler is detected for each of times. After 7 days of curing, concrete samples show a very tight correlation between the compressive strength and density. After 28 days of curing, the values of compressive strength and density are too dissipated to exhibit any dependence. The different character of micro-fillers affects the mentioned properties in different ways. Differences among the properties of specific concrete samples are significant after 365 days of curing too, but after this time the hydration reactions, strength development and various changes in the microstructure of materials become slower and more stable. Except the short-time (7 days) results, a weak correlation between the compressive strength and the density of concretes containing various kinds of a micro-filler was detected (see Fig. 6). It is different comparing the standard knowledge about the tight dependence between these two parameters, and it suggests that each kind of a microfiller influences it in a different way.

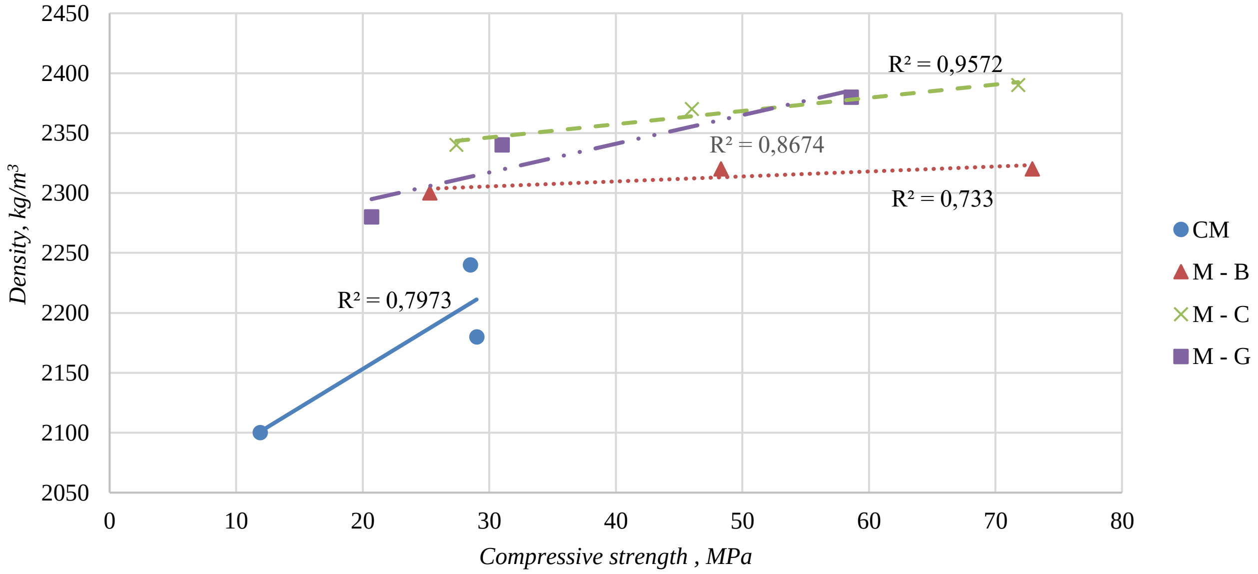

Fig. 5. Interactions between the density and compressive strength of tested concretes, evaluated after 7, 28 and 365 days of curing

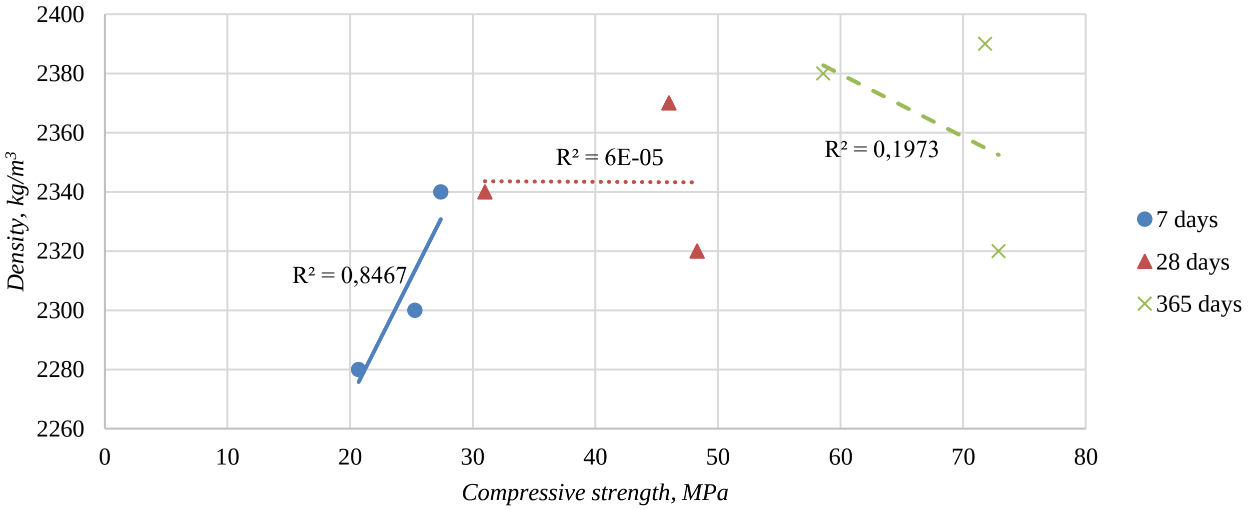

Fig. 6. Interactions between the density and compressive strength of concretes containing micro-fillers, evaluated by the kind of a micro-filler

In the case of interactions between the density and the water absorption capacity, there are no definite relationships for all samples, corresponding to standard relationships (higher is the density, lower is the absorption). As for the frost resistance, the M-B mixture shows the highest water absorption capacity and the lowest frost resistance coefficient. Because of the same water/cement ratio and air-entrainment admixture, differences in the water absorption capacity can be attributed to the character of a micro-filler. Brick powder in the M-B mixture leads to a more serious damage during frost resistance testing. The CM and M-C mixtures show a similar behavior in the case of interaction between the water absorption capacity and the frost resistance coefficient. A tight correlation between the water absorption capacity and the frost resistance coefficient can be observed in concrete samples after 365 days of curing. In case of specimens 28 days of age, there is no notable correlation.

Conclusion

The properties of concretes containing a high dosage of micro-fillers (brick, concrete and glass powders) were tested and evaluated. The following conclusions can be formulated:

- a high dosage of a micro-filler causes a higher density, and it increases with time;

- a high dosage of a micro-filler has a positive effect on the compressive strength, and it is increasing with time;
- all kinds of micro-fillers cause an increase in water absorption capacity in 28 days, while after a longer time the effect of the concrete powder is positive;
- a high dosage of a micro-filler has a positive effect on the frost resistance in 28 days; after 365 days the brick powder seems to cause a negative effect.

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DIDELIO KIEKIO MIKROUŽPILDŲ ĮTAKA BETONO SAVYBĖMS

S a n t r a u k a

Jau seniai aptarinėjamas konstrukcijų ir jų griovimo atliekų panaudojimas statybinėms medžiagoms gaminti, naudojant jas kaip stambius užpildus ar smulkius užpildus ar priedus. Šių atliekų savybes galima pagerinti jas modifikuojant specialia technologija.

Straipsnyje pateikiami betono su dideliu maltų konstrukcijų ir jų griovimo atliekų priedo kiekiu tyrimų rezultatai. Priedo milteliai buvo paruošti rūšiuojant betono, plytų, stiklo atliekas ir malant jas iki 250 μm. Šiuo priedu natūralūs 0/4 frakcijos mikroužpildai buvo keičiami tiek, kiek daugiausia leidžiama atsižvelgiant į technologines taisykles. Be ekologinių priežasčių (tausojami gamtiniai ištekliai), didelis mikro užpildų kiekis skirtas betono savybėms pagerinti. Pagrindinis tikslas – gauti itin paklausų didelio takumo betoną. Dėl to ir buvo optimizuojami kiti betono parametrai; vandens ir plastifikatoriaus dozavimas maišant buvo koreguojamas, kad atitiktų standartinius kriterijus.

Buvo tikimasi teigiamos mikroužpildų betono mikrostruktūroje įtakos sukietėjusiam betonui. Straipsnyje pateikti ir aptarti tankio, gniuždomojo stiprio, įgeriamumo ir atsparumo šaldymui bandymų rezultatai. Eksperimentai atlikti norint nustatyti atskirų maltų priedų įtaką betono savybėms ir jų pokyčiui laiko atžvilgiu (bandiniai tirti po 7, 28 ir 365 parų kietėjimo). Buvo nustatyta teigiama smulkiai maltų plytų, stiklo ir betono priedų įtaka betono gniuždomajam stipriui ir iš dalies atsparumui šalčiui, palyginti su kontroliniu betonu, tačiau teigiamas poveikis vandens įgeriamumui atsiranda tik po ilgo kietėjimo.

Reikšminiai žodžiai: mikroužpildai, didelio takumo betonas, tankis, gniuždomasis stipris.