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Impact of Technogenic Raw Materials on the Properties of High-Quality Concrete Composites

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***Abstract*—The paper presents the study of the impact of technogenic mineral filler (TMF) on the basic properties of high-quality concrete mixtures and concretes. There are principles of rational use of secondary technogenic raw materials in the form of concrete scrap, crushed bricks, ashes and slag mixtures in the technology of monolithic concrete. It is proved that the technogenic mineral filler, located between particles of a binder, significantly strengthens the cement stone by reducing the differential emptiness of the original water-cement paste in the direction of smaller pores and voids, which causes the formation of cement matrix with smaller capillary pores.**

Keywords—technogenic waste, secondary raw materials, concrete scrap, crushed bricks, ashes and slag mixture, disposal, concrete mix, high-quality concrete, mineral filler, efficiency, water separation on concrete mix, density and increased strength

I. Introduction

The disposal of technogenic waste, generated in almost all spheres of human activity, primarily in the industry, becomes extremely important for the whole world in the 21st century. The Russian Federation is not an exception in this matter because it has huge industrial base, which annually produces more than 7 billion tons of solid waste [1]. In recent decades the Chechen Republic alone has accumulated large volumes of solid waste in the form of ashes and slag mixtures, concrete scrap, crushed bricks, etc., which are of great interest for the construction materials industry. Naturally, such technogenic raw materials are suitable for use in the technology of construction and composite materials only after their mechanical, mechanochemical or other special processing.

One of the rational ways to dispose the above-mentioned technogenic raw materials is their secondary use in the technology of binders and concretes in the form of floured mineral fillers.

A large number of works in our country and abroad [2-5] are devoted to the study of the impact of fine-dispersed technogenic mineral fillers (TMF) on the structure and properties of cement stone and concrete. Currently, many scientists indicate the positive effect of mineral fillers on the basic properties of concrete mixtures and concretes thus saving the binder consumption to a large degree [6-8].

II. Methods and Materials

The mixtures for the production of control samples were mixed in the MM-1A mixer (mortar mill). The specific surface area of powdered bulk materials was defined via DSH-12 (device of Sominsky and Hodakov).

Among the nondestructive testing of concrete strength, the methods for complete destruction were used on hydraulic presses IP-500 and MP-1000 Nutcracker according to GOST 10180-2012.

The fine-dispersed grinding products of technogenic raw materials with different characteristics (Table 1) such as a filler of concrete scrap, ceramic crushed bricks (CCB), ashes and slag mixtures (ASM) and substandard small quartz sand were used in experimental studies as dispersed mineral fillers.

TABLE I. MICROFINE MINERAL FILLER ADDITIVES

No.	Filler		Specific surface area (SSA), m^2/kg
	Full name	Abbreviated name	
1	Technogenic mineral filler (TMF) made of concrete scrap	TMF made of concrete scrap	571
2	Technogenic mineral filler made of ceramic crushed bricks (CCB)	TMF made of CCB	592
3	Technogenic mineral filler made of ashes and slag mixtures (ASM)	TMF made of ASM	560
4	Mineral filler made of small quartz sand	MF made of small quartz sand	476

All TMFs were subject to grinding in the laboratory vibrating mill VM-20-EX to a specific surface area of 450-600 m^2/kg for 5 minutes.

At the first stage, the influence of the degree of concrete mixtures on rheological and strength characteristics of concrete was studied. Comparative tests were also carried out to obtain the dependencies of various properties for concrete mixtures and concrete on the type of fine-milled TMF.

It is known that the filler is found in a concrete mixture or replaced equally by cement or sand. In our case, TMF made of concrete scrap was added to concrete mix with the sand that replaced some part of a small filler. The test structure of concrete of B40 class by compression strength, obtained during the tests was as follows: C (cement) = 460 kg/m^3; M (macadam) = 960 kg/m^3; S (sand) = 780 kg/m^3; A (additives) = 5.0 kg/m^3; W (water) = 170 kg/m^3. Fine-milled mineral filler was introduced in the amount from 5 to 25 % by weight of cement with sand replacement. Linamix PC superplasticizer was used as an additive. The crushed stone fraction made 5-20 mm.

III. RESULTS

The test results demonstrated the dependences of workability, strength and density of concrete on TMF filling (Figures 1-4).

According to results obtained from the experimental data, the fine-milled TMF differently contributes to the improvement of technological, physical and mechanical characteristics of the concrete mixture and concrete. Thus, the mobility of the concrete mixture with bigger proportion of filler increases with the use of denser mineral fillers with the lowest water demand (for example, fillers from ASM and quartz sands).

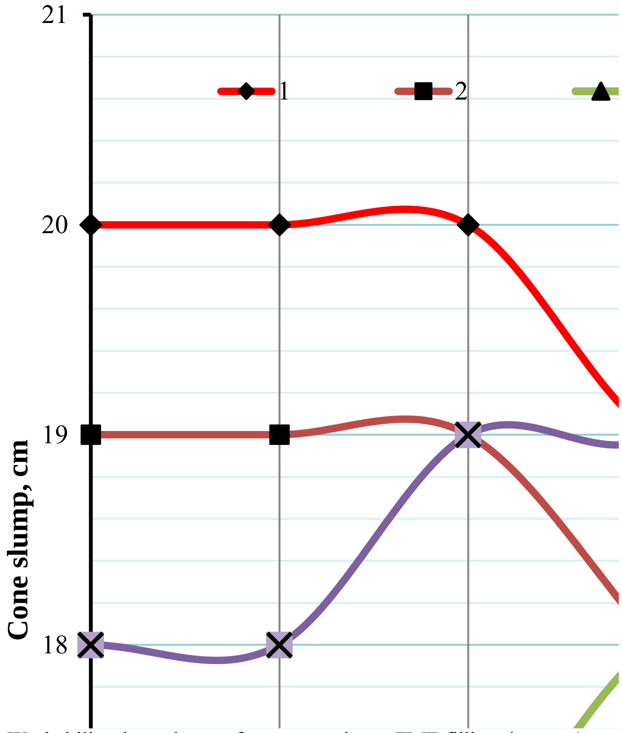

Fig. 1. Workability dependence of concrete mix on TMF filling degree: 1 – TMF made of concrete scrap; 2 – the same mix made of CCB; 3 – the same mix made of ashes and slag mixtures; 4 – the same mix made of small quartz sand

TMF from a concrete scrap and CCB almost equally promote the decrease in mobility of a mix. It is explained by the fact that after its introduction into a mix, the water demand considerably increases, as water absorption of these fine-milled technogenic mineral fillers is much higher in comparison with others.

The analysis of scientific works by authors [9-12] showed that the fine-milled filler effectively affects the parameters of water demand and water separation in the concrete mixture. Clearly, the degree of such influence will depend on the type of a filler. We compared the above four types of fine-milled technogenic mineral fillers.

In order to make it easier to establish the impact of fine-milled technogenic mineral filler on the water separation in the concrete mixture, the composition of the test concrete structure was specifically selected as the cast cone sediment M5 (mobility) with a small overconsumption of the liquid phase and water separation nearly 0.8-1.0 %.

Water separation of concrete mixture was determined after settling in a measuring vessel according to item 7 of the GOST 10181-2014 “Concrete mixtures. Test method”.

According to the GOST method, the concrete mixture was placed in a measuring vessel and condensed on the shaking table, depending on the mixture workability in accordance with item 7.3.2 of the GOST 10181-2014 (mixture M5 – vibration time is 10 seconds). The level of the concrete mixture shall be (10±5) mm below the upper edge of the measuring vessel.

The measuring vessel, covered with a vapor-proof sheet, was left for 2 hours in this position.

Every 15 minutes the separated water was taken with a pipette.

Upon completion of the experiment, the water separation of the concrete mixture was determined by the following formula:

$$I_W = \frac{m_W}{\rho_W \cdot V_{c.m.}} 100$$

where m_w – mass of water separated during the experiment, g;

ρ_w – water density taken as 1 g/cm^3;

$V_{c.m.}$ – volume of compacted concrete mixture in a measuring vessel, cm^3.

Delamination (water separation) of concrete mix shall not exceed the values given in GOST 7473-2010 “Concrete mixes. Technical conditions” (Table 2).

The dependence of the water separation in the concrete mixture on the degree of TMF filling is shown in Figure 2.

The obtained dependences of TMF type and volume on water separation in concrete mixtures revealed that TMF made of CCB had the biggest effect preventing the water separation in the concrete mixture (decrease from 0.9 to 0.1 %). The filler of concrete scrap takes the second place. In addition, it significantly reduces the water separation in the concrete mixture, but slightly concedes to TMF made of CCB at its flow rate is within the range of 10-20% by cement weight. TMF made of ASM and small quartz sand show approximately the same results, indicating a decrease in water separation from 0.9 to 0.4-0.5 %.

TABLE II. REQUIREMENTS FOR DELAMINATION OF CONCRETE MIX

Mobility or stiffness of the mixture	Delamination of concrete mix, %, no more than	
	Water separation	*Mortar separation*
S1 – S5	0.2	3
M1 – M2	0.4	3
M3 – M5 and S1 – S6 (slump cone spread)	0.8	4

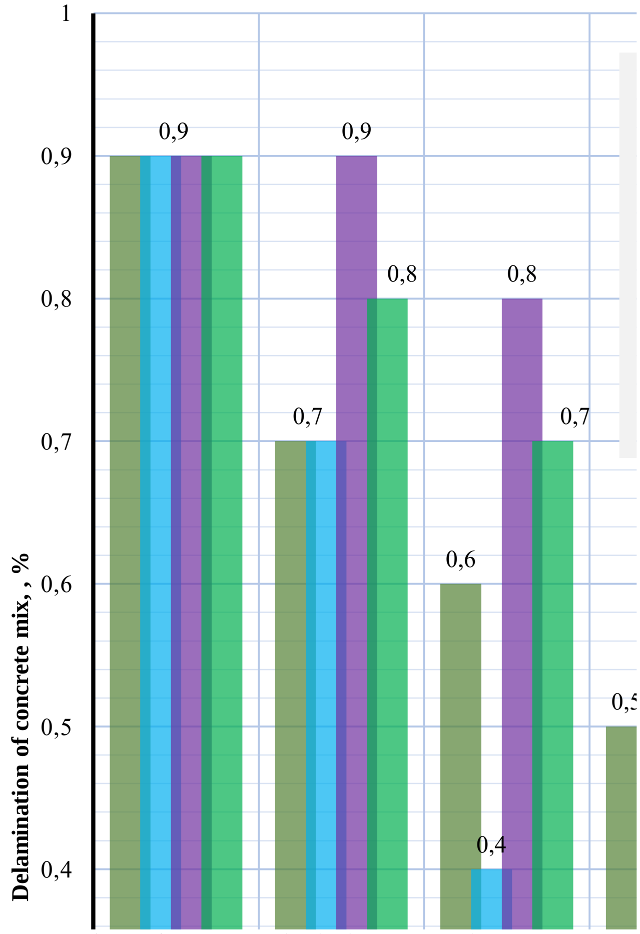

Fig. 2. Dependence of water separation in the concrete mixture on TMF filling degree

In addition, it was found that the introduction of TMF into concrete mixture leads to noticeable increase in the strength and density of concrete (Figures 3 and 4). At the same time, TMF made of concrete scrap was more effective than the rest in terms of physical and mechanical properties of concrete, and TMF made of CCB was less effective.

The most positive effect of TMF on the above indicators in concrete and concrete mixture is observed after the dose of about 15 % of the cement mass. After recalculation, concrete is about 70 kg of filler per 1 m^3. Upon further increase in the TMF content, the strength of concrete is significantly reduced. This is explained by the fact that after the increase in the TMF ratio above the optimal value, a large filler with a dense packing of particles turns into a state of “floating filler structure” characterized by less durable matrix.

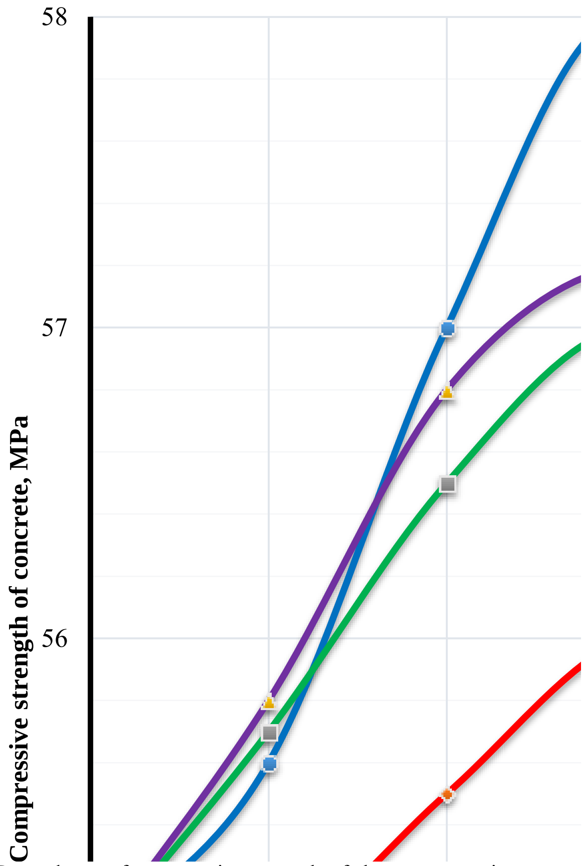

Fig. 3. Dependence of compressive strength of the concrete mixture on TMF filling degree

Notable strength of concrete increases with TMF made of concrete scrap, thus this filler may contain up to 20-25 % until complete hydration of cement particles with binding properties after the second grinding of the filler. Such feature of TMF made of concrete scrap allows classifying hydraulically active fillers for concrete.

IV. Conclusions

Thus, we introduced the rational reuse methods of technogenic raw materials in the monolithic concrete technology.

We have identified several main factors of TMF positive influence on the structure of concrete mixtures, physical and mechanical characteristics of concrete:

- prevention of water separation in concrete mixtures by increasing TMF volume concentration and positive effect can reach 90 % or more depending on the filler's type;

- noticeable decrease in the total porosity of cement stone and increase of its density with increasing the TMF volume concentration;

- influence on the water demand of concrete mixtures by a number of different mineralogical fillers;

- strengthening of concrete stone by reducing the differential emptiness of the initial water-cement paste in the direction of smaller pores and voids with the location of fine granules between the particles of a binder, which causes the cement matrix formation with smaller capillary pores.

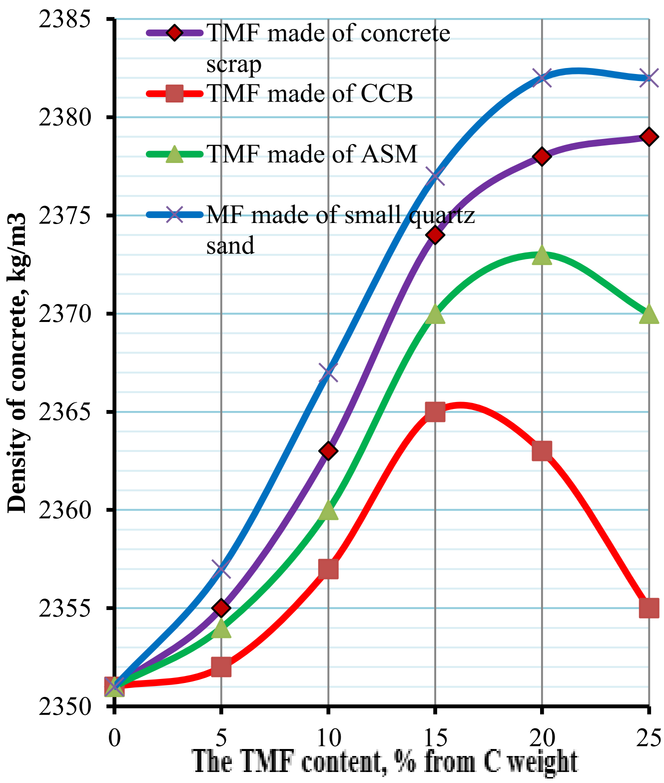

Fig. 4. Dependence of density of the concrete mixture on TMF filling degree

There is a proof that TMF, located between the particles of the binder, significantly strengthens the cement stone by reducing the differential emptiness of the initial water-cement paste in the direction of smaller pores and voids. That causes the cement matrix formation with smaller capillary pores. At the same time, the greatest strengthening effect after the introduction of a fine-milled filler equals 5-10% of the design strength and is typical for the TMF made of concrete scrap.

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