

# Technology of small architectural forms for the improvement of rural settlements

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**Abstract.** Improvement of rural settlements is an urgent task to create attractive living conditions, preserve cultural traditions, develop ethnic tourism and create a unique look for the villages and villages of the Don region. It is advisable to make small architectural forms of concrete, which is a versatile and durable material that allows any designer's creative idea to be realized. The performed studies have established that it is rational to produce small architectural forms from fine-grained self-compacting mixtures with screenings of stone crushing of rocks of the Don region. The experiments have shown that in a fine-grained self-compacting mixture, the optimal dosage of ordinary limestone crushing screenings is 20%, and sandstone crushing screenings can reach 33%. This is explained by an increase in the liquefaction effect of the anionic superplasticizer due to its lower adsorption on fine particles of sandstone grains, which have a predominantly negative surface charge. The mobile production of small architectural forms from fine-grained self-compacting concretes with stone crushing screenings on the territory of crushing and sorting plants will allow organizing a promising business and creating new jobs for residents of rural settlements.

## 1 Introduction

In the Russian Federation, for the implementation of the national project "Housing and Urban Environment" (within the framework of the federal programs "Formation of a Comfortable Urban Environment" and "Smart City"), urban centers for the development and implementation of large-scale smart projects in the field of a comfortable urban environment have been created in many megacities. The state program for the development of agriculture and regulation of markets for agricultural products, raw materials and foodstuffs also includes the task of providing comfortable conditions for citizens living in rural areas, including young families and young professionals, in the list of activities of the departmental target program "Sustainable Development of Rural Areas".

In the Rostov region, which is an agricultural region and the most important supplier of agricultural products for the country, about 2 million people live in rural areas (42% of the total population). The improvement of social facilities, public spaces and the local area in rural settlements is an urgent task aimed at creating a unique appearance of the villages and

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towns of the Don region, preserving cultural traditions and developing ethnic tourism. To form a comfortable living environment, various design objects are required, a special place among which is occupied by small architectural forms (SAF), which combine functionality and aesthetic appeal at the same time.

Small architectural forms are subdivided into three types by purpose: utilitarian (urns, lanterns, fences, non-standard benches, parking stops), decorative (art objects, fountains, flower arrangements, artificial reservoirs), health-improving (sports facilities). But, despite the variety, all products should be uniform in style, since, filling the space and being in the field of view of a person, they shape his aesthetic taste and contribute to a harmonious coexistence with the environment.

Traditionally, small architectural forms are made of metal, wood, fiberglass and concrete, which is one of the strongest and most durable materials, making it easy to embody any designer's creative idea. When designing small architectural forms, the natural landscape and climatic conditions of their operation must be taken into account. Therefore, for concretes for SAF, which are mainly used for organizing open spaces, additional requirements are imposed, which are significantly different from ordinary concretes. In addition to high indicators of durability (frost resistance, water resistance, crack resistance), concrete must meet the requirements of aesthetics in terms of the quality of the front surface, appearance and artistic expression. In addition, a specific feature of SAF is their complex geometric shape and small size, which complicates the use of traditional methods of manufacturing products based on concrete mixtures with a large aggregate. To meet all of the above requirements, it is rational to organize the production of SAF from fine-grained self-compacting concrete using vibration-free technology [1, 2].

Fine-grained concretes, traditionally made from natural quartz sands, become technically ineffective for the production of high-strength and durable products due to the high water demand of the mixture. An alternative to natural sands can be small aggregates from screenings of crushing rocks in the production of crushed stone. In Russia, annually at the enterprises for the production of crushed stone, a huge amount of crushing screenings is accumulated, the total volume of which is about 35 million m<sup>3</sup>, including screenings of magmatic rocks - 15 million m<sup>3</sup>, and screenings of sedimentary carbonate rocks - 20 million m<sup>3</sup>. But until now, the demand for them in the construction industry is low due to the lamellar and needle-like shape of the grains and the high content of dust particles. In the Don region, crushing and screening plants located in the northwestern part of the Donetsk coal basin produce crushed stone for construction work from sandstone and limestone. On the territory of these enterprises located in rural areas, it is advisable to organize the production of concrete and reinforced concrete products with the integrated use of crushing screenings. Its rational use in concrete and mortar mixtures is prepared and substantiated by the Russian standard GOST 31424-2010 "Nonmetallic building materials from screenings of crushing of dense rocks in the production of crushed stone".

Self-compacting concretes, related to innovative building materials, require a scientific approach in the design of the composition and reasonable use of raw materials [3, 4]. For self-compacting concrete mixtures, the rational consumption of all components must be determined as a result of optimization of the granulometric composition of the mineral part, and the plasticizing additive should be chosen individually for a specific cement type, taking into account its compatibility with all components of the mixture [5-7]. Only highly effective modifying additives, thanks to innovative developments in the field of construction chemistry, can provide concrete mixtures with the required spreadability, provided that its cohesion and non-segregation is preserved [8, 9].

Previous studies have established [10-12] that when using crushing screenings in self-compacting fine-grained mixtures, a technological contradiction arises: an increase in the proportion of strong screening grains increases the strength of concrete, but at the same time

the spreadability of the concrete mixture and its ability to self-compacting decrease. Therefore, the purpose of this work was an experimental assessment of the possibility of the integrated use of crushing screenings of various rocks of the Don region in self-compacting fine-grained mixtures in the production of small architectural forms.

## 2 Materials and Methods

As binders for the studies, we used no additive Portland cement of the CEMI 52.5N and CEMI 42.5N classes, as well as sulfate-resistant Portland cement with a mineral additive of the CEMII / A-P42.5N-SR class. The technical characteristics of the cements are presented in table 1.

**Table 1.** Main Characteristics of the Cements

Parameter, measuring unit	CEMI 52.5N Russian Standard 31108	CEMI 42.5N Russian Standard 31108	CEMII/A-P 42.5N-SR Russian Standard 22266
Compression strength in 28 days, MPa	59.7	51.1	50.0
True density, g/cm <sup>3</sup>	3.19	3.10	3.15
Bulk density, kg/m <sup>3</sup>	1010	1120	1170
Normal consistency of cement paste, %	29.0	24.75	27.50
Specific surface, cm <sup>2</sup> /g	4054	3520	4015
Mineral admixture (gaize), %	–	–	10.2
Efficiency coefficient under heat curing	0.76	0.79	0.77

Materials of the Don region were used as fillers for the preparation of fine-grained concrete mixture. Among them, there are natural quartz sands and screenings of crushing of limestone and sandstone. The main characteristics and particle size distribution of small aggregates are presented in tables 2 and 3, respectively.

**Table 2.** The main characteristics of the fine aggregate

Parameter, measuring unit	Sand (S1) Russian Standard 8736	Sand (S2) Russian Standard 8736	Dropout (D1) Russian Standard 31424	Dropout (D2) Russian Standard 31424
True density, g/cm <sup>3</sup>	2.65	2.65	2.65	2.66
Bulk density, kg/m <sup>3</sup>	1355	1415	1420	1400
Fineness modulus	1.48	1.22	3.26	2.66
Group of sand	Very small	Very small	Increased size	Large
Voidness, %	48.9	46.6	46.4	47.4
Dust and clay particles concentration, %	1.2	1.1	0.9	1.0

**Table 3.** Grain composition of fine aggregates

Name	Name of the balance	Residues, % by weight, on sieves					Passage through a sieve with a grid N016, % by weight	Fineness modulus M <sub>F</sub>
		2.5	1.25	0.63	0.315	0.16		
Sand (S1)	Private	0.29	0.83	1.88	44.86	47.58	4.56	1.48
	Complete	0.29	1.12	3.00	47.86	95.44	100.0	
Sand (S2)	Private	0.22	0.65	1.34	28.93	56.75	12.11	1.22
	Complete	0.22	0.87	2.21	31.14	87.89	100.0	

Limestone crushing screening (D1)	Private	36.52	16.68	15.59	10.60	8.77	11.84	3.26
	Complete	36.52	53.20	68.79	79.39	88.16	100.0	
Sandstone crushing screening (D2)	Private	24.12	14.38	14.21	13.50	18.53	15.26	2.66
	Complete	24.12	38.50	52.71	66.21	84.74	100.0	

To regulate the properties of self-compacting mixtures, plasticizing and water-retaining additives of the BASF and SIKA brands were used, which confirmed its high efficiency in previous studies [13]. The characteristics of chemical modifiers are shown in Table 4.

**Table 4.** Characteristics of chemical additives

Trade mark	Name	Characteristics
BASF	MasterGleniumACE430 (MG430)	Superplasticizer on the polycarboxylate ether basis with rapid strength generation
	MasterPolyHeed 3545 (MPH3545)	Superplasticizing and high-water-reducing additive based on polyaryl and polycarboxylate esters
	MasterMatrix 100 (MM100)	Viscosity modifier based on an aqueous solution of a high-molecular synthetic polymer
SIKA	Sika ViskoCrete 20 HE (VC 20HE)	Superplasticizer based on an aqueous solution of modified polycarboxylate
	Sika ViskoCrete 24 HE (VC 24HE)	Superplasticizer on the water-based modified polycarboxylate ethers for reinforced high-strength concrete items production with rapid strength generation
	Sika Stabilizer 4R (ST.4R)	A starch-based stabilizing additive that increases the resistance of concrete mixes to delamination

During the research, the average density of concrete mixtures was determined according to the method of the Russian standard GOST 10181. The workability of fine-grained self-compacting mixtures was established by the diameter of the concrete cone outflow according to the method EN 12350-8: 2010.

The concrete spreading diameter of the mixture SF, cm, was determined by measuring the diameter of the spreading cake  $d_1$  and  $d_2$  by tape measure in two mutually perpendicular directions:

$$SF = \frac{d_1 + d_2}{2} \quad (1)$$

Manufacturing, storage and compressive strength testing of cube specimens of fine-grained concrete with a nominal rib size of 100 mm was carried out according to the method of the Russian standard GOST 10180.

### 3 Results and Discussion

The analysis of the granulometric composition of fine aggregates showed that the studied natural sands of the Rostov region belong to the group of very fine and are characterized by the stability of the composition. Screenings of crushing of rocks do not differ in the stability of the composition, especially for the dust-like fraction, the content of which in the composition of the screenings can vary from 12 to 17%. The presence of a large number of fine particles, the specific surface of which is practically equal to the specific surface of the cement, significantly increases the water consumption to ensure the required workability of the concrete mixture. The use of such materials in concrete mixes dramatically increases the consumption of cement, so its use is possible only after substantiating tests in concrete.

In this work, we investigated fine-grained self-compacting mixtures with crushing screenings, the characteristics of which are shown in Table 5. In concrete mixtures based on no additive Portland cement (compositions 1M-11M), to assess the possibility of complex application of crushing screenings, we used ordinary screening with a dusty fraction playing the role of a mineral filler. In fine-grained mixtures based on sulfate-resistant Portland cement with a mineral additive (compositions 12S-19S), only coarse screening fractions were used to enrich the sands. Screening was introduced in an amount of 20 to 40% instead of part of the natural sand. To assess the effect of grain size composition, type and amount of screening on the basic properties of fine-grained self-compacting mixtures, compositions with various superplasticizers and viscosity modifiers were prepared. The compressive strength of fine-grained self-compacting concrete is shown in Figure 1.

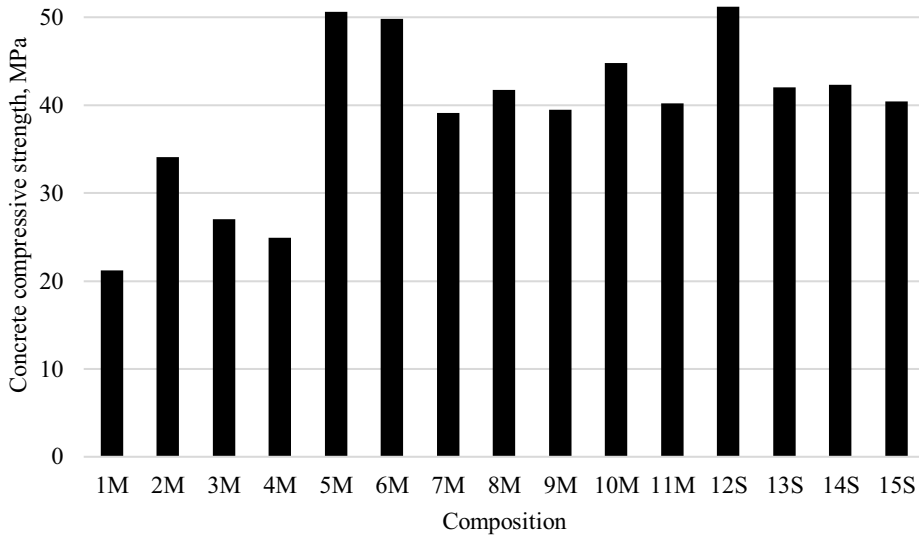
Experimental studies have shown that in a fine-grained mixture on natural sand S1, the optimal dosage of ordinary screening of crushing of limestone D1 is 20% (composition 2M). When replacing very fine sand with screenings, containing mainly grains with sizes from 0.63 to 5.0 mm and a dust-like fraction in the amount of 9% of the cement mass, the water demand of the concrete mixture decreases by 23%. In comparison with the 1M composition, this technological factor leads to an increase in the strength of fine-grained concrete up to 34.1 MPa, but at a nominal cement consumption of 400 kg / m<sup>3</sup> this is not a sufficient condition to ensure SAF durability indicators. Therefore, at the next stage of research, fine-grained mixtures were prepared with a nominal cement consumption of 500 kg / m<sup>3</sup>. Analysis of mixtures of compositions 5M and 6M, prepared on natural sand S1 and ordinary screenings of crushing of sandstone D2, indicates that an increase in the consumption of binder and chemical modifiers ensures high flowability of the mixtures and the achievement of high concrete strength even with a screening dosage of 33%. In our opinion, this is due to an increase in the efficiency of the anionic superplasticizer MG ACE430 due to its lower adsorption on fine particles of sandstone grains, which have a predominantly negative surface charge.

**Table 5.** Characteristics of fine-grained self-compacting mixtures and concrete

Composition	Type of sand	The type and size of particle dropping out, mm		Cement type and consumption, kg/m <sup>3</sup>			Admixture type and gauging per 1 m <sup>3</sup> , kg					Water-cement ratio	Cone flow diameter, cm	Concrete compressive strength, MPa	
				CEM I 52.5N	CEM I 42.5N	CEMII/A-P42.5N-SR	MPH3545	MG ACE430	MM100	VC 20HE	VC 24HE				ST.4R
1M	S1	-	-	380	-	-	6.0	-	-	-	-	-	0.90	55.0	21.2
2M	S1	D1 (0.0-5.0)	20	397	-	-	6.4	-	-	-	-	-	0.66	56.0	34.1
3M	S1		25	388	-	-	6.2	-	-	-	-	-	0.78	55.0	27.0
4M	S1		30	385	-	-	6.2	-	-	-	-	-	0.83	57.0	24.9
5M	S1	D2 (0.0-5.0)	33	-	507	-	-	7.6	-	-	-	-	0.52	66.0	50.6
6M	S1		33	-	499	-	-	6.7	1.5	-	-	-	0.57	65.0	49.8
7M	S1	-	-	501	-	-	8.0	-	-	-	-	-	0.56	55.0	39.1
8M	S1	D 2	20	510	-	-	8.3	-	-	-	-	-	0.52	55.0	41.7

9M	S2	D2 (2.5-5.0)	20	515	-	-	8.4	-	-	-	-	0.56	53.0	39.5	
10M	S1		30	519	-	-	8.3	-	-	-	-	0.51	69.0	44.8	
11M	S2		30	512	-	-	8.2	-	-	-	-	0.55	54.0	40.2	
12S	S2	D2 (2.5-5.0)	30	-	-	518	-	-	-	10.4	-	0.49	66.0	51.2	
13S	S2		30	-	-	503	-	-	-	10.1	-	2.5	0.56	63.0	42.0
14S	S2		30	-	-	505	-	-	-	-	10.0	-	0.51	70.0	42.3
15S	S2		30	-	-	494	-	-	-	-	9.9	2.47	0.54	68.0	40.4
16S	S2	D2 (2.5-5.0)	40	-	-	382	-	-	-	5.72	-	0.63	50.0	28.2	
17S	S2		40	-	-	373	-	-	-	5.59	-	1.86	0.73	50.0	21.0
18S	S2		40	-	-	364	-	-	-	-	5.46	-	0.76	45.0	29.4
19S	S2		40	-	-	362	-	-	-	-	5.43	1.81	0.78	52.0	24.5

To obtain fine-grained self-compacting mixtures and concretes based on it with stable quality indicators for the enrichment of natural fine sands, we used fractionated screenings of sandstone D2 with grain sizes: 0.63-1.25; 1.25-2.5; 2.5-5.0 mm. Screening was introduced in the amount of 20 and 30% instead of part of the sand, so that the grain size composition of the filler met the recommended characteristics (compositions 8M - 11M).



**Fig. 1.** Compressive strength of fine-grained self-compacting concretes with rock-crushing screenings of 1M-15S compositions

The results obtained showed that mixtures with natural sand S1 and fractionated screenings with a grain size of 0.63-5.0 mm have stable self-compacting properties and provide high-strength concrete (compositions 8M and 10M). When 30% of natural sand is replaced with coarse screening fractions in an optimal ratio, the water demand of the mixture decreases, but the spreadability of the mixture increases to 69 cm, and an increase in the

proportion of strong screening grains in the structure of concrete increases its compressive strength by 15% (composition 10M). At the same time, a new generation additive - superplasticizer MPH 3545 - plays a decisive role in the formation of the basic properties of fine-grained self-compacting concretes. It simultaneously has a water-retaining and highly water-reducing effect, it reduces the risk of water separation and stratification during the laying of mixtures, ensuring that the concrete reaches the required quality indicators. In the course of research, it was also found that for self-compacting mixtures, it is ineffective to use crushing screenings with sand S2, containing more than 12% of fine particles less than 0.16 mm in size (compositions 9M and 11M). Even with high water consumption, the required spreading of the mixtures was not achieved.

At the final stage of research, an assessment of the properties of self-compacting concretes for SAF, operating under conditions of possible sulfate corrosion, was carried out. For the preparation of concrete mixtures, sulfate-resistant Portland cement was used with a mineral addition of flask in an amount of 10%, and natural sand S2 and single-fraction screening of sandstone D2 with grain sizes of 2.5-5.0 mm were used as fine aggregates. Studies have shown that with the optimal dosage of screening in an amount of 30%, established at the previous stage of the experiments, and the content of cement paste in a volume of at least 425 liters, fine-grained concrete mixtures are characterized by increased spreadability, and concretes based on it - high strength (compositions 12S-15S). It was noted that the presence of the stabilizing additive ST.4R gives the mixtures high homogeneity and cohesion (compositions 13S and 15S), but increases its water demand by 5-10% and, therefore, reduces the strength of concrete by 10-15%.

It was found that with an increase in the dosage of fractionated screening up to 40% and a decrease in the volume of cement paste, fine-grained concrete mixtures of compositions 16S - 19S are not self-compacting, since they do not reach a spread with a diameter of 55 cm. The presence of a large number of screening particles with a developed debris and rough surface increases the forces friction between acute-angled contacts, which leads to the structuring of the system, an increase in the viscosity of the mixtures and a decrease in its spreadability. Even an increase in the dosage of the superplasticizer and the presence of a stabilizer did not provide the mixtures with the ability to self-compact.

Experimental studies have shown that the production of small architectural forms from fine-grained self-compacting concrete with screenings for crushing rocks of the Don region is technically achievable and economically justified. The complex use of crushing screenings will reduce the consumption of natural sand, the cost of which is 3-4 times higher than the cost of crushed raw materials, and, therefore, will reduce the cost of fine-grained concrete. It is rational to organize the production of SAF from fine-grained self-compacting concretes with crushing screenings on the territory of crushing and sorting plants or in the immediate vicinity of enterprises, since they are located in rural areas where the main consumers of products live. The accumulated experience of processing stone crushing screenings in the Russian Federation shows that its integrated use requires a preliminary dry air classification using cascade-gravity classifiers. In such installations, due to the action of the force of the ascending air flow and the force of gravity acting on the particles of the initial material, a method of separating fine-grained materials according to the size, density and shape of particles is implemented [14]. After separation into fractions, the classification products must be transported to the concrete mixing unit and dosed in the amount specified in the selection of concrete compositions.

The authors of current work have developed a variant of the production of small architectural forms from fine-grained self-compacting mixtures with crushing screenings of the Don region. The design solution, focusing on seasonal sales of products, provides for the mobile production of concrete products in an open landfill equipped with a concrete pump and a truck crane. For the rhythmic production of reinforced concrete products, an

intensification of concrete hardening is required. Previous studies have established [15, 16] that the strength gain of self-compacting concretes with effective modifiers based on polycarboxylates at the initial stage is slow, which indicates the retarding effect of additives on the processes of cement setting and concrete hardening. Strength, frost resistance, water resistance and a number of other indicators of the purpose of concrete directly depend on the correct setting of the temperature and the duration of the thermal effect. Therefore, in the manufacture of SAF in the factory for accelerated hardening and the formation of a finely porous low-defect structure of fine-grained self-compacting concretes with crushing screenings, it will be necessary to use low-temperature heat treatment modes [17]. When organizing the production of reinforced concrete products in low-depth pit-type chambers equipped with autonomous heat generators, the duration of preliminary curing of concrete should be at least 5 hours, the rate of temperature rise should not exceed  $10^{\circ}\text{C}/\text{h}$ , and the maximum heating temperature should not exceed  $60^{\circ}\text{C}$ . Such a mode of operation of the technological line with a turnover of one day will ensure the rhythmic release of the LFA of the required quality.

## 4 Conclusions

The studies have shown that in the production of small architectural forms from fine-grained self-compacting mixtures, it is possible to use complex screenings of crushing rocks of the Don region. Analysis of the grain size composition of natural sands and screenings of stone crushing showed that in self-compacting mixtures their use is possible only in conjunction with highly water-reducing and water-retaining additives after substantiating tests in concrete. The performed studies have established that in a fine-grained self-compacting mixture, the optimal dosage of ordinary limestone crushing screenings is 20%, and sandstone crushing screenings can reach 33%. This is explained by an increase in the liquefaction effect of the anionic superplasticizer due to its lower adsorption on fine particles of sandstone grains, which have a predominantly negative surface charge.

To ensure the required quality and aesthetics of SAF based on fine-grained self-compacting concretes, it is necessary to use fractionated crushing screenings to enrich natural fine sands. Replacing 30% of natural sand with large fractions of sandstone crushing screenings reduces the intergranular voidness of the aggregate, reduces the water demand of the concrete mixture, while ensuring its high fluidity. An increase in the proportion of strong grains in the structure of fine-grained concrete in an optimal amount increases its physical and mechanical properties.

The production of small architectural forms from self-compacting concrete with stone crushing screenings on the territory of crushing and sorting plants will meet the main criteria for sustainable development of rural areas, as it will allow organizing a promising business and creating new jobs for residents of rural settlements. The proposed version of the SAF production testifies to the investment attractiveness of the innovative design solution. When considering other options of interest to potential Customers and Investors, detailed study will be required using updated data [18-20].

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