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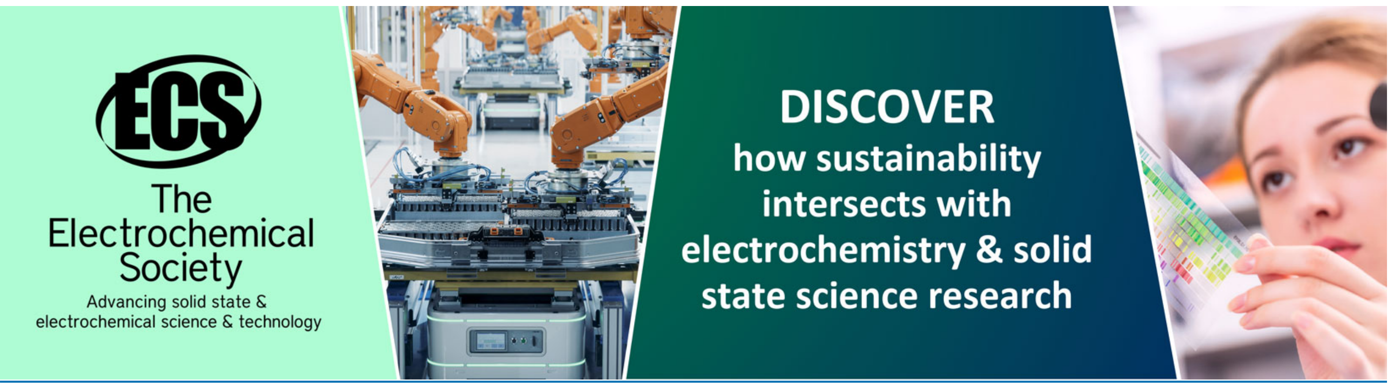

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Application of sea sand for 3D concrete printing

A V Sharanova, A O Tovpinets and M A Dmitrieva
Immanuel Kant Baltic Federal University, 14 Nevskogo St, Kaliningrad 236016, Russia

E-mail: a.sharanova@gmail.com

Abstract. The paper shows the promising use of sea sand for additive technologies in construction. The use of sea sand reduces the setting time of the concrete mix and increases the initial strength compared to conventional quarry construction sand. A comparative analysis of the characteristics of sea and quarry sands was performed. It has been experimentally proven that the use of sea sand instead of quarry sand in fine-grained concrete mix leads to a decrease in the setting time of the fresh mix and an increase in the strength of concrete samples. The flexural strength and compressive strength of samples containing sea sand at the age of 28 days increases by 35.7% and 16.7%, respectively, comparing to samples containing quarry sand.

1. Introduction
Construction using the additive technologies, or concrete 3D printing, is a new and promising method in the construction industry. The main difference of this method compared to traditional construction is layer-by-layer growing of structural elements without the use of formwork and the use of fine-grained concrete mix as a building material. Concrete for 3D printing should quickly set and gain sufficient initial strength to maintain the weight of the layers printed above. Concrete mixture must have good fluidity for free extrusion through the extruder nozzle, and at the same time sufficient viscosity to maintain the printed form. Fine additives based on industrial waste (fly ash, silica fume), or additives of thermally treated clay (metakaolin) give to concrete the necessary properties [1].

It is known that the use of sea sand as a fine aggregate for concrete leads to a decrease in setting time and an increase in the initial strength of concrete [2-7]. But at the same time, due to the presence of chloride ions in the sea sand, the durability of concrete with sea sand is lower than that of ordinary concrete, since chlorides cause corrosion of steel reinforcement and generally reduce the service life of concrete structures [4]. It becomes possible to assume that the use of sea sand as a fine aggregate can be effective in constructions, where reinforcement with polypropylene, basalt or other types of fibers is used as an alternative to steel reinforcement. In addition, the use of mineral additives, such as fly ash, silica fume, metakaolin leads to the blocking of chloride ions. Due to this fact, there is an increase in long-term strength and service life of concrete structures [2, 5, 6]. In [7], it is noted that in metakaolin-modified concrete, chloride ions introduced from seawater can be immobilized through the formation of hydrocalumite (Friedel's salt), which improves the corrosion resistance of concrete and makes the addition of metakaolin to sea concrete more beneficial. Therefore, sea sand is promising for use as fine aggregate to concrete for construction using additive technologies.

2. Materials and methods
The paper compares the effect of two types of sand on the characteristics of fine-grained concrete. According to the results of previous work on the selection of the composition for additive technologies

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in construction, the optimal composition was determined that meets the requirements of concrete 3D printing. Two mixtures of fine-grained concrete are made of this composition; in the first case, sea sand is used as fine aggregate, in the second case, quarry sand is used.

2.1. Materials

The following materials were used for the preparation of samples:
- Portland cement Eurocem super 500, CEM I 42.5H, Petersburg Cement;
- Sand: for the composition No. 1: sea sand from the coast of the urban-type settlement Yantarny, Kaliningrad region; for the composition number 2: sand from the quarry near village Sinyavino, Kaliningrad region;
- Polypropylene fiber: length of 12 mm, thickness of 35 μm, country of origin: Russia;
- Silica fume (SF): wastes of the metallurgical industry, country of origin: Poland;
- Highly active metakaolin (MK): white, country of origin: Russia, Chelyabinsk region, Synergo;
- STACHEMENT 1267 hyperplasticizer based on polycarboxylates for the production of ready-mixed concrete: country of origin: Poland.

Characteristics of sand are presented in Table 1.

Table 1. Sand characteristics.

Location of origin	Size group	Fineness modulus	Content of dust and clay particles (%)	True density (kg/m^3)	Bulk density (kg/m^3)	Voidness (%)
Coast	Medium	2.1	-	2612	1474	43.6
Quarry	Fine	2	2.2	2642.5	1330	49.7

All the characteristics were determined according to Russian State standards GOST 8736-2014 "Sand for construction work. Specifications" and GOST 8735-88 "Sand for construction work. Testing methods".

The appearance of the sand is shown in Figures 1 and Figure 2. The images were obtained using an optical electron microscope.

Figure 1. Sea sand.

Figure 2. Quarry sand.

The consumption of materials per 1 m^3 of the concrete mixture is given in Table 2.

Table 2. Materials per 1 m^3.

W/C ratio	Cement (kg/m^3)	Sand (kg/m^3)	Water (l/m^3)	Silica fume (SF) (kg/m^3)	Metakaolin (MK) (kg/m^3)	Fiber (kg/m^3)	Hyperplast. (l/m^3)
0.66	545	1168	360	156	78	1.2	11.7

2.2. Methods
Two compositions of fine-grained concrete were made. In the first case, sea sand was used as fine aggregate, in the second case, quarry sand was used. For each of the compositions were determined: the setting time using Vicat apparatus with a needle (GOST 30744-2001); the consistency of the cement paste by the Vicat apparatus with a plunger (GOST 30744-2001); the consistency of the fresh mixture by the flow table test (GOST 310.4-81); the workability by the cone penetrometer test (GOST 5802-86); the flexural strength and compressive strength of samples 40x40x160 mm (GOST 310.4-81) at the age of 1, 3, 7 and 28 days.

3. Results
The test results for the comparison of compositions containing different sands are given in Table 3. The strengths of the samples are presented in graphs (Figures 3, 4) and in Table 4.

Table 3. Compositions containing different sands.

Composition No.	Initial setting time	Final setting time	Consistency by the Vicat apparatus (mm)	Flow table test (mm)	Cone penetrometer test (mm)
1	1h 40 min	2h 30 min	5	148.5	47
2	2h	2h 40 min	37	145.3	46

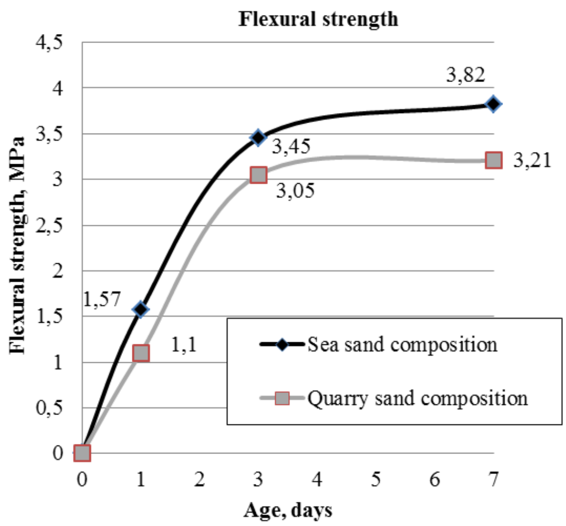

Figure 3. Flexural strength at 1, 3 and 7 days.

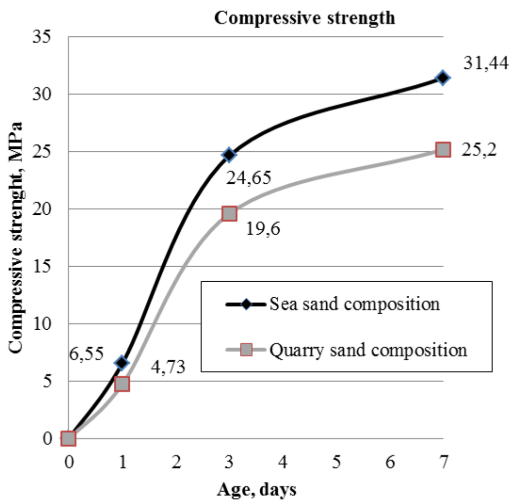

Figure 4. Compressive strength at 1, 3 and 7 days.

Table 4. The strengths of the samples.

Composition No.	Sand type	Flexural strength (MPa)				Compressive strength (MPa)			
		1 day	3 days	7 days	28 days	1 day	3 days	7 days	28 days
1	Sea sand	1.57	3.45	3.82	5.09	6.55	24.65	31.44	36.66
2	Quarry sand	1.10	3.05	3.21	3,75	4.73	19.60	25.20	31.40

The flexural strength and compressive strength of samples with sea sand at the age of 28 days increases by 35.7% and 16.7%, respectively, comparing to the samples with quarry sand.

4. Conclusion

As a result of the research, it was proved that the use of sea sand as an aggregate in fine-grained concretes leads to a decrease in the setting time and an increase in the initial strength. It can be assumed that the use of sea sand as an aggregate in concrete is promising for additive construction methods and is relevant for coastal areas. It should be noted that the use of sea sand in compositions for 3D printing requires further, more thorough research. There is a need to define additional characteristics of sea sand, such as salt content, mineralogical composition, etc. The investigation of joint work of mineral additives and salt-containing sand components, the appearance of salt on the surface of the finished concrete, its influence on the concrete structure are insufficient and need further study.

Acknowledgement

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