STUDY ON SOME DURABILITY PROPERTIES OF HIGH-STRENGTH FINE-GRAINED CONCRETE USING SALINE SAND AND CRUSHED AGGREGATE

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Abstract

This paper presents the results of research on some durability properties of high-strength fine-grained concrete made from saline sand and crushed aggregates with different mixing ratios. The specific mechanical properties and durability of concrete when working in a saline environment were tested, including compressive strength, water absorption, sulfate durability, and the alkali-aggregate reaction of concrete. The results show that: when replacing regular aggregate in C50 concrete with a mixture of salted sand and crushed aggregate with an appropriate mixing ratio, the concrete has a compressive strength of over 50 MPa, and water absorption reduces significantly. The sulfate and alkali-aggregate reaction are guaranteed to meet the requirements set forth by the standards for sulfate and alkali-resistant durability concrete. This result has great significance in the study and application of high-strength fine-grained concrete made from saline sand to build the constructions in marine and island environments.

Keywords: *Fine-grained concrete; saline sand; ability to absorb water; sulfate durability; alkali-aggregate reaction.*

1. Introduction

Recently, research into making concrete from non-traditional materials has been very interested both at home and abroad. Reality shows that the demand for concrete in construction is constantly increasing. The source of raw materials of river sand and crushed stone for cement concrete production is in a state of over-exploitation, even at the risk of resource depletion and adversely affecting the ecological environment. That requires research into using alternative materials for traditional aggregates to reduce adverse impacts on ecologic balance and habitat. In addition, ordinary concrete in some harsh working conditions like the marine environment has revealed certain limitations due to the characteristics of regular concrete structures cannot meet the particularity requirements for structures when working in those harsh environmental conditions. Therefore, this fact also poses the problem of finding more suitable raw materials to make non-conventional concrete to meet the respective special requirements.

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High-performance fine-grained concrete made from saline sand is a type of concretes made from non-conventional materials, meeting both requirements mentioned above. It has both contributed to minimizing the exploitation of river sand sources at present and applied this type of concrete for constructions in marine and coastal environments with technical features that ensure to meet stricter usage requirements compared to conventional concrete.

Studies in the world have shown that dredged sea sand has the same physical and mineralogical characteristics as mainland sand [1]. Concrete made from saline sand can achieve grades from M-20 to M-40 or more, depending on how the saline sand is used [2-6]. To improve compressive strength, the popular solution is to use superplasticizers. In that case, the concrete strength can be up to 90% compared to concrete using river sand of the same grade [7]. When combining the solution of using superplasticizers, mineral additives with small aggregates, concrete made from sea sand (replacing all river sand) can achieve a compressive strength of over 40 MPa.

The short-term concrete strength is tested and found to be suitable for constructions in marine and coastal environments. But the degree of strength stability, expressed in terms of water absorption, strength degradation, the durability criteria associated with the marine environment such as sulfate resistance, alkali resistance - aggregate of concrete has not been specially studied and comprehensively. Previously published results show that the conclusions drawn about the durability of concrete using sea sand are not the same from different studies in the world. It may be because the strength of concrete depends on the origin of the material used [8]. Fine-grained concretes with strength below 40 MPa using saline sand have been researched in Vietnam. But the number of studies on fine-grained concrete with strength higher than 40 MPa is very scanty. The durability properties have not been completely investigated and evaluated. Therefore, the comprehensive studying of this issue for high-strength concrete (over 50 MPa) using sea sand in the waters of Vietnam is necessary and has great scientific significance. Studying this issue helps evaluate the applicability and make recommendations when building marine structures in the area.

2. Materials and research methods

2.1. Cement

The type of cement used in this study is But Son Portland cement (PC40) with chemical composition and physical and mechanical properties that meet the requirements of TCVN 2682:2009. Mineral composition: $\%C_3S$ = 51.74%; $\%C_2S$ = 24.2%; $\%C_3A$ = 8.16%; $\%C_4AF$ = 10.35%.

Table 1. Chemical composition of cement

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	MKN
21.49	5.40	3.49	63.56	1.40	1.65	0.15	0.70	1.20

2.2. Aggregates

The aggregate mixture used includes saline sand and crushed aggregate (chippings). In that, crushed aggregate with grain size is selected in the range (0.6-9.5) mm. The properties of the aggregates according to ASTM C33 are in Table 2.

Table 2. Some physico-mechanical parameters of aggregates

No	Items	Unit	Values	
			Saline sand	Crushed
1	Density	g/cm^3	2.63	2.744
2	Porosity volume mass	g/cm^3	2.495	2.471
3	Water saturated volume mass	g/cm^3	2.549	2.569
4	Absorption of water	%	1.238	3.944
5	Totally dry compacted volumetric	g/cm^3	1.485	1.652

The aggregate mixture consisting of saline sand and crushed aggregate is mixed in different weight ratios, including saline sand: crushed aggregate with 40:60, 50:50, or 60:40. Figure 1 shows the grain composition curve of this aggregate.

The aggregate mixture has a particle composition that meets the specified standards for aggregates used in making concrete.

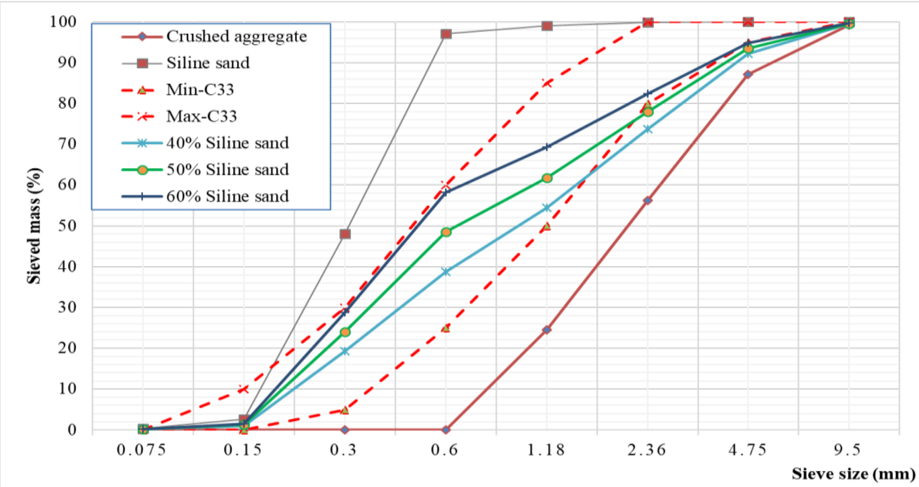

Figure 1. Grading curves of aggregate mixes.

2.3. Additives and other binders

This study used BASF ACE-8509 superplasticizer that is high water reducing (Type F according to ASTM C494), which helps develop early strength.

In addition to the main binder, But Son PC40 cement, other binders used in the study include Vung Ang fly ash (ensure to meet technical requirements according to TCVN 10302:2014 and ASTM C618 (type F); high activity index) and Hoa Phat blast furnace slag (ensure to meet TCVN 11586:2016, activity index at 28 days is over 95%).

2.4. Test method

The test concrete mix grades (CP1-CP5) are designed based on a combination of absolute volume method, refer to TCVN 10306:2014 and experiment, to achieve the following concrete strength at 28 days is 50 MPa.

Table 3. Composition of concrete mix

I. Testing concrete mixtures											
Mixes	**Water/ adhesives**	**Saline sand**	**Crushed aggregate**	**Water**	**Cement**	**Fly ash**	**Blast furnace slag**	**Total of aggregate**	**Crushed aggregate**	**Saline sand**	**Superp-lasticizer**
		(%)	(%)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
CP1	0.29	40	60	205	400	150	150	1467	880	587	3.50
CP2	0.29	50	50	205	400	150	150	1463	731	731	3.50
CP3	0.29	60	40	205	400	150	150	1456	583	874	4.00
CP4	0.29	50	50	205	350	150	200	1460	730	730	3.20
CP5	0.29	50	50	205	300	150	250	1458	729	729	3.00
II. Control concrete mixtures											
Mixes	**Water/ adhesives**	**River sand**	**Crushed stone**	**Water**	**Cement**	**Fly ash**	**Blast furnace slag**	**Total of aggregate**	**Crushed stone**	**River sand**	**Superp-lasticizer**
		(%)	(%)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
CP6	0.31	42	58	149	485	0	0	1822	1061	761	5.34

The authors have used the beam concrete mixture (CP6) - Nhat Tan Bridge Construction Project (Hanoi) to compare some necessary criteria. The testing concrete mixtures are shown in Table 3.

The compressive strength of fine-grained concrete is determined according to TCVN 3118-1993, the water absorption of concrete is determined according to TCVN 3113:1993 on a 100 mm cube test specimen.

The sulfate resistance of concrete is determined based on applying the ASTM C1012/C1012M-15 standards (method for testing the sulfate resistance of cement mortar samples can use active mineral admixtures). This durability is considered through the change in grout rod length after six months of curing. If the length of the test sample changes less than 0.1%, the concrete is sulfate resistant. When the length change is less than 0.05%, the concrete is high sulfate resistant. According to ASTM C1012, the sulfate solution used is a 5% Na_2SO_4 solution. The test specimen used in this study is a bar sample with dimensions of (25×25×285) mm. The method for determining the elongation of test specimens is similar to that for the determination of dry shrinkage.

Alkali - aggregate durability is assessed through the potential for the alkaline reaction of aggregate, determined according to ASTM C1260 standard on sample size (25×25×285) mm.

3. Results and discussion

3.1. Compressive strength

The compressive strength of concrete is determined based on applying TCVN 3118-1993 standard (Figure 2); The average compressive strength results of 3 test pieces for each concrete graded showed in Figure 3.

Figure 2. Failure pattern of the specimen subjected to compressive load.

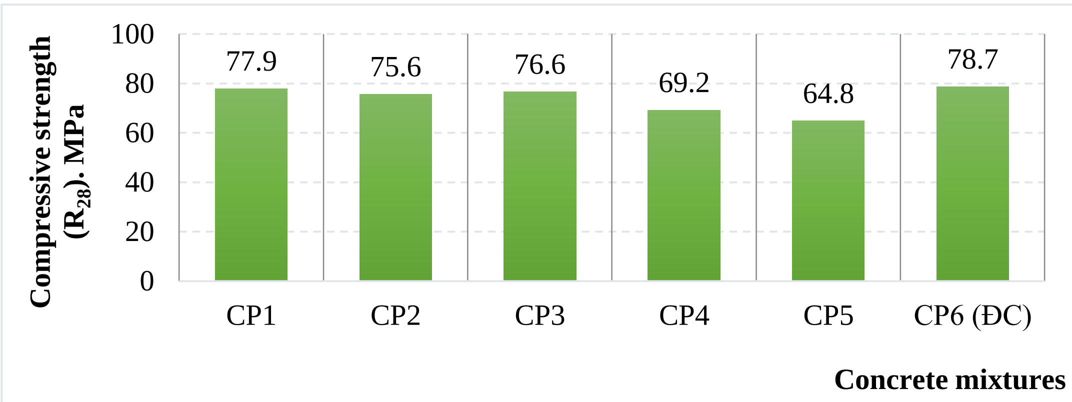

Figure 3. Compressive strength of concrete.

When using saline sand with content from 40% to 60% by weight of aggregates, the rest is crushed aggregate, mineral additives (fly ash and blast furnace slag with the content of 150 kg each), the strength of concrete (at 28 days) decreased very little compared to the control concrete. Strength value of 3-grade concrete CP1, CP2, CP3 is 77.9, respectively; 75.6; 76.6 MPa, respectively reaching 99%, 96% and 97% of the reference concrete strength (CP6). Rising the amount of blast furnace slag is up to (200÷250) kg and reducing the corresponding cement makes the concrete strength decrease considerably. The value of concrete strength of 2 gradations of CP4, CP5 reached 69.2 MPa respectively (decreased by 13.1% compared to the initial strength) and 64.8 MPa (reduced by 17.7% compared to the initial strength). However, in all cases, using saline sand and crushed aggregate instead of traditional aggregate has shown high efficiency in ensuring post-fabricated concrete strength above 50 MPa.

3.2. Water absorption

The water absorption of concrete determined according to TCVN 3113:1993 at the age of 28 days is shown in Figure 4.

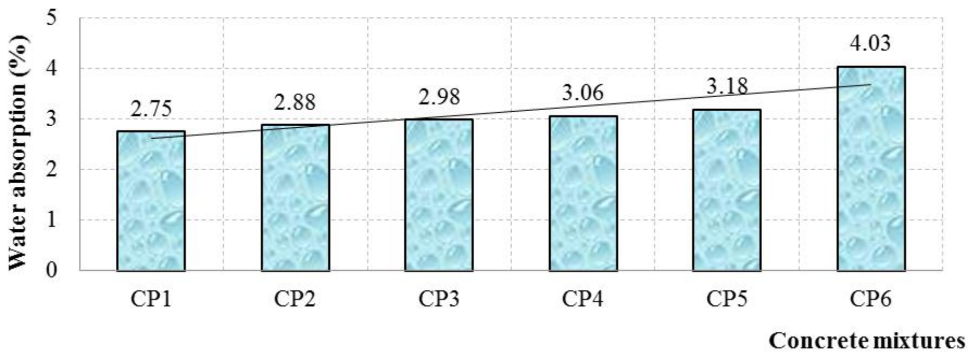

Figure 4. Water absorption of concrete.

The results show that the test concrete has a water absorption from 2.75% (CP1) to 3.18% (CP5), smaller than the control concrete mixture (CP6 has water absorption of 4.03%). That reflects the structure of concrete when made from a mixture of crushed aggregate and saline sand having a higher solid, more watertight than the control concrete. It is explained by the simultaneous effect of beneficial factors like the presencing of saline sand (with a smaller magnitude modulus than that of ordinary river sand) and the mixture of mineral additives (fly ash and blast furnace slag have superfine particle size). They have an important role in filling the voids between aggregate particles, forming a denser concrete structure. Thereby they reduce water permeability for fine-grained concrete made from saline sand.

3.3. Sulfate durability

The sulfate durability of fine-grained concrete is evaluated based on the application of the ASTM C1012 standard. The experimental results are shown in Figure 5.

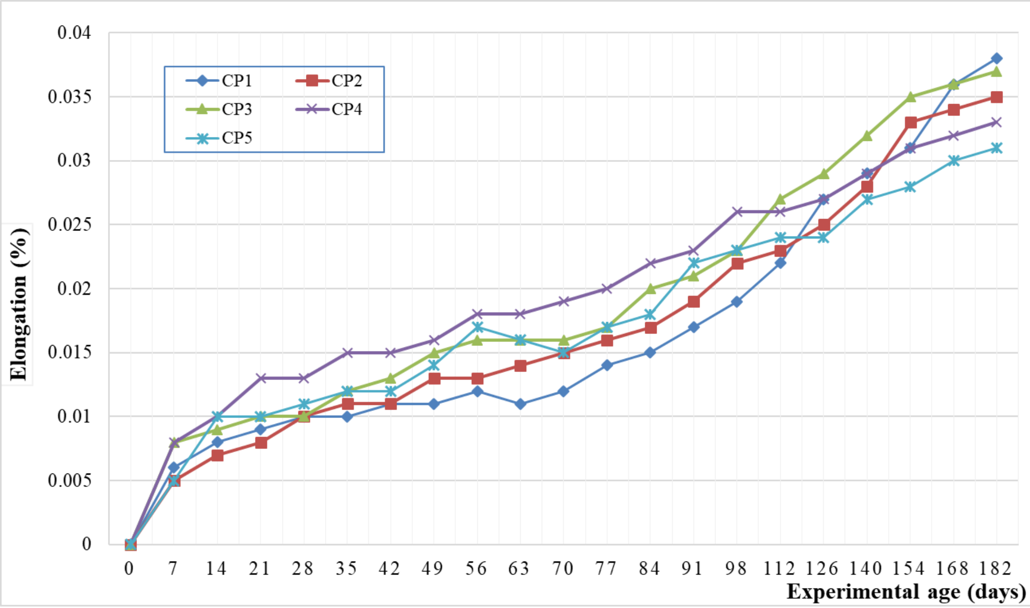

Figure 5. Elongation of test piece when immersed in Na_2SO_4 solution.

The elongation of the test samples of the concrete mixes using saline sand increased gradually over time. The most significant expansion is in the early stage of solidification (≤ 14 days), with the dilation reaching from (0.005÷0.01)%. That happened at most of the concrete mixes tested. After that, the expansion took place at a slower rate and was relatively stable until the end of the experiment (in this case, 182 days). That is explained by the fly ash hardly participating in the reaction in the early stages of solidification. It is only beneficial to enhance the sulfate resistance of concrete in the later solidification stage [9]. In the early stages, both fly ash and blast furnace slag presence slowed down the formation of concrete strength. Therefore, the solid phase formation process slows down [10-12], the concrete structure has not achieved high density, leading to stronger absorption of liquid phase compounds. Therefore, the expansion also increases faster than the late stages of the concrete age.

The experimental results showed that the elongation of the test sample reached the maximum value of 0.038% (at the time of soaking in sulfate solution for 182 days). This value is smaller than the value specified (0.05%) by ASTM C1012, so it allows asserting that the tested concrete has high sulfate resistance. It shows that the sulfate durability of concrete was improved if compared with ASTM C1012 and with some previously published studies on concrete using normal aggregates or aggregates that are non-saline sand [13, 14]. In which, CP4, CP5 mixtures (using 150 kg fly ash additive, (200÷250) kg blast furnace slag, and saline sand at 50% of aggregate weight) give better results than others.

Experimental results for CP5 mixture (using the ratio of saline sand: crushed aggregate equal to 1:1, fly ash 150 kg/m^3 of concrete, blast furnace slag 250 kg/m^3 of concrete) are the best. The specimen length expansion is not abnormal at the age of the concrete. In this test, this is considered the best grade for making concrete with high sulfate durability.

When concrete works in an environment containing sulfate ions, its strength change is also a concerning matter. It directly affects the bearing capacity of the structure. To consider and evaluate this change, the authors experimented to determine the strength of concrete when immersed in a 5% Na_2SO_4 solution (Table 4).

Table 4. Concrete strength when soaked in sulfate solution at 7, 28 and 120 days

Experimental age / **Mixes**	**7 days**			**28 days**			**120 days**		
	R_7^{dd} (MPa)	R_7^n (MPa)	k_7 (%)	R_{28}^{dd} (MPa)	R_{28}^n (MPa)	k_{28} (%)	R_{120}^{dd} (MPa)	R_{120}^n (MPa)	k_{120} (%)
CP1	56.2	56.5	-0.5	75.9	77.9	-2.6	79.9	78.9	1.3
CP2	55.1	55.6	-0.9	76.1	75.6	0.7	76.8	76.7	0.1
CP3	56.1	58.2	-3.6	74.7	76.6	-2.5	78.3	76.5	2.4
CP4	49.5	50.7	-2.4	71.7	69.2	3.6	82.1	79.3	3.5
CP5	46.9	45.9	2.2	65.2	64.8	0.6	81.4	78.3	4.0
CP6 (C)	73.4	73.2	0.3	75.5	78.7	-4.1	84.4	92	-8.3

The strength of fine-grained concrete when immersed in a sulfate solution is compared with the strength when immersed in water, of the same age, through the coefficient k_t (expressing the increase in the compressive strength of the concrete):

$$k_t = \frac{R_t^{dd} - R_t^n}{R_t^n} \text{x}100\%$$

where R_t^{dd} is the compressive strength of concrete soaked in 5% Na_2SO_4 solution, at t days, (MPa); R_t^n is the compressive strength of concrete immersed in water, at t days, (MPa).

The results are shown in Figure 6. The results show that 4 out of 5 mixtures of concrete have strength when soaked in sulfate solution is lower than concrete strength when soaked in water at the age of 7 days (coefficient $k_t < 0$). However, at the age of 28 and 120 days, the experimental mixtures (CP1 ÷ CP5) gave coefficient $k_t > 0$.

It shows that the rate of strength development of concrete soaked in sulfate solution is faster and faster. At a late age, the strength value of concrete soaked in sulfate solution is also higher than that of the same age concrete immersed in water. This process is in contrast to the control concrete mix (CP6).

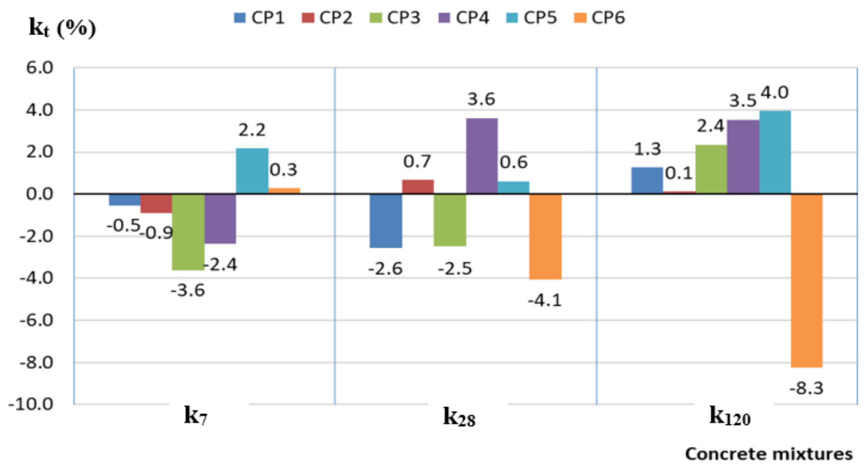

Figure 6. Degree of increase in compressive strength of concrete.

The reason is that the blast furnace slag particles are very fine, with high activity. It interacted with the products of the cement hydration reaction ($Ca(OH)_2$), increasing the solid phase in the concrete and reducing the number of sulfate compounds infiltrating the concrete. At the same time, fly ash reduces sulfate corrosion because it chemically binds with free lime in the binder compounds to help limit free lime to react with sulfate ions or reduce the permeability of concrete, keeping the concrete intact; sulfate compounds do not penetrate the concrete. The use of fly ash also reduces the alumina content, which limits the reaction between alumina and sulfate ions [11]. Therefore, the use of fly ash and finely ground blast furnace slag helps to improve the sulfate resistance of concrete, helps the concrete to increase its strength even when immersed in a solution with sulfate ions.

3.4. Alkali-aggregate reaction

The alkali-aggregate reaction test of concrete is carried according to the ASTM C1260 standard. The results are shown in Figure 7.

The results showed that the concrete samples at all test grades had the maximum elongation after 16 days in the range of (0.059÷0.067)%. This result is less than the value specified by ASTM C1260 (0.1%). Therefore, using aggregate as in this test will not cause an alkali-aggregate reaction in the concrete.

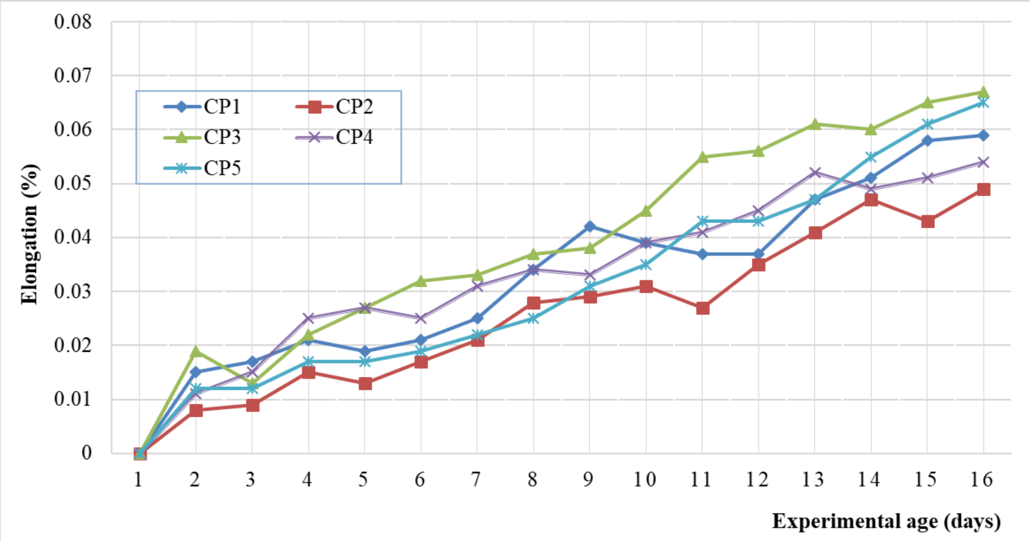

Figure 7. Elongation of test piece when immersed in NaOH solution.

Among the tested mixtures, the best results were witnessed in CP2 mix (with the ratio of using salted sand aggregate: crushed aggregate equal to 1:1 and the amount of fly ash additive by finely ground blast furnace slag with 150 kg/m^3 of concrete). Most of the elongation values of CP2 mixture concrete samples (15/16 measured values) are lower than those of the remaining concretes mixes. Therefore, this can be seen as the best mix in meeting the requirements for making concrete with high alkali-aggregate reaction.

4. Conclusions

From the presented research results, some conclusions drew as follows:

- It is possible to make high-strength fine-grained concrete from saline sand. The compressive strength of concrete (at 28 days) is 64.8 to 77.9 MPa. The aggregate mixing ratio of 40% saline sand and 60% crushed aggregate gives the best strength results (at 28 days) among the test grades.

- The use of saline sand and an admixture of fly ash and blast furnace slag with appropriate concentrations creates a denser concrete structure than conventional concrete. The water absorption reduces significantly.

- When curing concrete in a solution containing sulfate ions (Na_2SO_4 5%), there is an increase in strength at a late age (at 120 days), reaching higher strength than concrete having normal curing. The test to measure the length of the specimen according to ASTM C1012 gives the expansion is less than 0.05%, allowing the conclusion that the tested concrete has high sulfate durability.

- Tested concrete has no potential risk of alkali-aggregate reaction. The length expansion according to ASTM C1260 gives results less than 0.1%.

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NGHIÊN CỨU MỘT SỐ ĐẶC TRƯNG VỀ ĐỘ BỀN CỦA BÊ TÔNG HẠT NHỎ CƯỜNG ĐỘ CAO CHẾ TẠO TỪ CÁT NHIỄM MẶN VÀ CỐT LIỆU NGHIỀN

Trần Văn Cương, Nguyễn Thanh Sang, Đinh Quang Trung

Tóm tắt: *Bài báo trình bày kết quả nghiên cứu một số đặc trưng về độ bền của bê tông hạt nhỏ cường độ cao được chế tạo từ cát nhiễm mặn và cốt liệu nghiền với các tỉ lệ phối trộn khác nhau. Các tính chất cơ lý và độ bền đặc thù của bê tông khi làm việc trong môi trường nhiễm mặn đã được kiểm tra, bao gồm: cường độ chịu nén, độ hút nước, độ bền sunfat và độ bền kiềm - cốt liệu của bê tông. Kết quả cho thấy khi thay thế cốt liệu thông thường trong bê tông cấp độ bền C50 bằng hỗn hợp cát nhiễm mặn và cốt liệu nghiền với tỉ lệ phối trộn phù hợp, bê tông có cường độ chịu nén đạt trên 50 MPa và độ hút nước giảm đi đáng kể. Độ bền sunfat và độ bền kiềm - cốt liệu đảm bảo đáp ứng các yêu cầu được quy định bởi các tiêu chuẩn chuyên ngành cho bê tông chịu sunfat và bê tông chịu kiềm. Kết quả này có ý nghĩa lớn trong nghiên cứu ứng dụng bê tông hạt nhỏ cường độ cao chế tạo từ cát nhiễm mặn vào xây công trình làm việc trong môi trường biển và hải đảo.*

Từ khóa: Bê tông hạt nhỏ; cát nhiễm mặn; độ hút nước; độ bền sunfat; độ bền kiềm - cốt liệu.

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