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Influence of sediment additions on the mechanical behavior of fiber-reinforced concrete in aggressive environments

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Abstract:

Introduction/purpose: The use of supplementary cementitious materials (SCM) in construction has gained popularity due to their ability to improve the mechanical properties and environmental sustainability of concrete. This study aimed to investigate the potential of utilizing waste materials, specifically marble powder (MP) and dam sediment (DS), as partial replacements for cement in self-compacting concrete (SCC). The primary objectives were to recycle these waste materials and assess the durability and strength of SCC exposed to aggressive chemical environments.

Methods: In this study, cement was partially replaced with 40% MP, 40% DS, and a combination of 20% MP and 20% DS. The performance of such concrete was evaluated through compressive strength tests conducted for 28 days. Durability was assessed by exposing the concrete to chemical attacks from hydrochloric acid (HCl), sulfuric acid (H_2SO_4), and sodium sulfate (Na_2SO_4) solutions. Mass loss due to these chemical attacks was also measured.

Results: The concrete incorporating MP demonstrated compressive strengths similar to that of the control concrete, achieving 37.61 MPa at 28 days. The concrete with DS exhibited lower strength (31.81 MPa) and showed higher resistance to HCl (ML = 38.78%) compared to the MP concrete (ML = 40.74%). Additionally, all concrete samples exhibited good resistance to sulfuric acid due to the formation of expansive ettringite which protected the concrete from further degradation.

Conclusions: The results indicated that both marble powder and dam sediment are viable supplementary materials for improving the mechanical properties and durability of SCC. The concrete with marble powder showed superior strength, while dam sediment contributed to enhanced acid resistance. The combination of these materials offers a sustainable solution for concrete exposed to aggressive environments.

Key terms: concrete (SCC), sediment, marble powder, fiber, mass loss, mechanical, aggressive environment.

Introduction

The process of dredging dam sediments is necessary to ensure water storage capacity. This process generates over 600 million cubic meters of dredged sediment yearly, while less than 1% is currently recycled. Sediment storage can significantly impact the development of ecosystems and coastlines downstream of major river systems (Sellaf et al, 2023). Sediments generally consist of soil residues, organic minerals, and other natural elements resulting from coastal erosion. These can be classified as organic and inorganic pollutants (heavy metals such as lead, chromium, mercury, salts, etc.). On the other hand, there is a growing demand for materials used in construction.

However, major obstacles and problems have been discovered in the sediment beneficiation process due to major differences in material properties and the quantities of salts and organic matter they contain, which can lead to high permeability and corrosion of reinforcement (Labiod-Aloui et al, 2014).

The deterioration of concrete elements exposed to aggressive sulfuric acid environments is a major durability issue affecting critical civil infrastructure's life-cycle performance and maintenance costs. Sulfuric acid present in groundwater or chemical waste or generated by the oxidation of sulfur compounds (e.g., pyrite) in backfill can attack the substructure protecting concrete elements (Bassuoni & Nehdi, 2007). Furthermore, concrete structures in industrial areas are vulnerable to deterioration due to acid rain, of which sulfuric acid is a major component (Thunuguntla & Gunneswara Rao, 2018).

Muhedin & Ibrahim (2023) studied the characteristics of concrete that used waste glass powder (WGP) in place of cement and sand. The results of laboratory tests were used to determine the compressive strength and separate tensile strength of concrete with 0%, 5%, 10%, 15%, and 20% partial replacement of sand and cement separately by WGP. The concrete compressive strength could be improved significantly at 7, 28, 60, and 90 days when using WGP as a partial replacement of cement at 5%, 10%, and 15% which can be considered a reasonable ratio.

Ranatunga et al. (2023) used coconut shell ash as a partial replacement for cement to reduce environmental impact while achieving the previously specified structural performance of concrete. The replacement percentage varies from 15% to 30% of the total content, and the optimum content for partial replacement is reached at 20% to achieve the targeted average compressive strength of 25 MPa.

Scherer et al. (2023) concluded that using rice hull ash and rock powders as a partial cement replacement could help investigate concrete durability in aggressive environments. The concrete containing these mineral admixtures showed better durability and less mass loss than the reference concrete. Concrete containing mineral admixtures showed better resistance to acid corrosion than Portland cement concrete.

Materials and methods

Materials used

The sediment used in this study was recovered in the discharge area of the Fergoug dam, located in theMohamadia region of Mascara (west Algeria). This dam was the first dredged dam in Algeria from 1986 to 1989, and it had over 10 million m3 of dredged sediment (Hammadi et al, 2011). This dredging was carried out with floating suction dredge extruders. Sediment (vases) are sucked into the dredge and discharged through a pipeline consisting of a floating and a fixed part of several hundred meters in length (Hammadi et al, 2011).

The thermal method was used to prepare the sediment following standard XP P94-047. After calcination in an oven at 450 °C, organic matter was removed. As a result, the dam sediments contain an organic percentage of 6.25%.

Marble powder was prepared from the remains of marble stones from workshops and quarries by placing it in a micro-diffusion device, crushing it, and then sieving it through a 2 mm sieve. These two specimens were subject to several laboratory identification tests using standard procedures adopted by the AFNOR and ISO standards NF P94-068 (AFNOR, 1998b), NF P94-057 (AFNOR, 1992), NF 94-056 (AFNOR, 1996), NF P94-054 (AFNOR, 1991) and NF P94-051 (AFNOR, 1993).

The chemical analysis of the specimens was carried out in accordance with NF EN 1744 (AFNOR, 1998a), and the results are presented in Table 1.

Gravel is traditional and commonly used on building sites. These aggregates were washed and then sieved to obtain 03 fractions 3/8, 8/15. The characteristics were determined according to standards, and we obtained the following: absolute density (2.62 g cm-3) and apparent density (1.40 g cm-3).

The cement used in this research is ordinary Portland cement (OPC) prepared from 76% clinker, 18% lime, and 6% gypsum. The chemical analysis of the cement is presented in Table 2. The densities of cement, sediment, and marble powder are approximately 3.2, 2.46, and 2.75 g cm-3, respectively.

In our experimental study, we used a crushed sand fraction (0/3) from the Tizi quarry in the southwest region of Mascara. Before use, the sand is washed to reduce impurities. The absolute density value has been estimated at 2500 kg m-3 le and a fineness coefficient of 2.78, with a water absorption capacity of around 2.4% and a cleanliness level of 78%. A 5% solution of sulfuric acid, hydrochloric acid, and sodium sulfate was chosen for the mix. Formal tests are carried out and prepared to test the concrete resistance to chemical attack.

In this study, all mixes were made with a water/cement ratio (w/c) set at 0.55. The sand/cement (S/C) ratio was 1:3 for all samples. Plasticizers were added to the mix to achieve similar workability. The plasticizer content ranged from 2% to 2.5% by weight of the binder.

Table 1 – Some properties of the investigated materials (Sellaf et al, 2023)

	Dam Sediment	Marble powder	Sand
Liquid limit (%)	32.28	35	20
Plastic limit (%)	15.09	13	Nul
Plasticity index (%)	17.19	22	Nul
Volume of blue VB (g cm-3)	4.5	5.2	0.39
Specific gravity	2,46	2.63	2.75
Apparent density (g cm-3)	1.26	1.45	1.53
Fineness modulus	1.2	1.35	2.78
Organic content (%)	6.25	0.05	Nul

Table 2 – Chemical compositions of the soils used in the study (Sellaf & Balegh, 2023)

Property	Dam sediment	Marble powder	Crushed sand	Cement
SiO_2 (%)	61.75	60,5	56,82	21,23
Al_2O_3 (%)	8.39	4,85	5,12	5,23
Fe_2O_3 (%)	0.71	11,85	0,16	2,34
CaO (%)	12.51	9,45	13,4	63,25
MgO (%)	0.37	1,22	10,38	2,01
NaOH (%)	Nul	0,08	0,07	0,15
CL (%)	Nul	0,05	0,05	0,01
$P.F_2$ (%)	16.27	12	14	5,78

Concrete mix-design

Our formulation study consists of formulating vibrated concrete and self-compacting concrete based on marble powder and/or Fergoug sediment as additions. The introduction of mineral additions leads to a modification of the porosity of cementitious matrix and influences the concrete mechanical and self-compacting characteristics.

The fluidity of self-compacting concrete is obtained by adding superplasticizers. This admixture must not be too high (close to saturation dosage). Otherwise, the concrete sensitivity to variations in water content will be increased, leading to problems of segregation and bleeding.

The formulation method used to design the self-compacting concrete compositions tested in this experimental study is an empirical method based on four points:

The self-compacting concrete formulation meets the mechanical strength criteria (fixed or desired) chosen from Bolomey's formula, see equation 1 (Denis, 2008):

$$\mathrm{F}'_{\mathrm{c}} = R_C\, G\, \left[\frac{L_{Equi}}{E_{eff} + Air} - 5\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

where

F'_C: compressive strength of concrete in (MPa),

R_C: compressive strength of cement in (MPa),

L_{Equiv}: cement + k. mineral additions (in kg),

Eeff: effective water quantity,

Air: air volume (in liter), and

G: granular coefficient.

Admixture dosage is calculated to limit segregation and bleeding. The superplasticizer dosage is determined experimentally from tests on fresh concrete, for which the spread must be between 60 and 70 cm.

The composition of the skeleton is optimized to reduce segregation and promote flow. To achieve this, the granulometric analysis of the concrete must fit into granular spindles (Figure1).

As regards the formulation of the corresponding vibrated concretes, their compositions were either obtained from those of the SCC, maintaining identical cement quantities and granular proportions, or from the Dreux-Gorisse method (high-performance vibrated concrete).

All the compositions studied during this research project are presented in Table 3. Aggregate quantities regarding soaked material mass (saturated aggregates on a dry surface) and admixture dosages for liquid product mass are given.

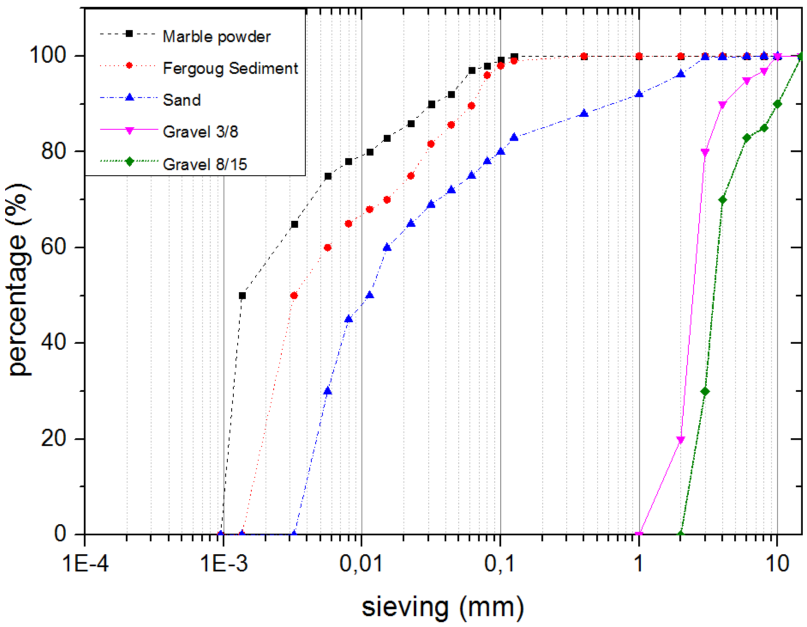

Figure1 – Aggregates grading curves

Table 3 – Composition of various concretes (kgm^{-3})

Composition (kg/m3)	Self-Compacting Concrete (SCC)			
	VC	SCCMP	SCCDS	SCCDSMP
Cement CEM I 42.5	350	210	210	210
Quartz powder	50	--	--	--
Marble powder (MP)	--	140	--	70
Dam sediment (DS)	--	--	140	70
Sand 0/3	962	962	962	962
Gravel 3/8	221	221	221	221
Gravel 8/15	636	636	636	636
water	192.5	192.5	192.5	192.5
superplasticizers	17.5	17.5	17.5	17.5

The self-compacting concrete (SCC) mix was designed following ACI-237R-07 (ACI Committee 237, 2007). Table 3 shows the different mix designs, taking additive contents into account. The mixing and production process for self-placing concrete is illustrated in Figure 2, as proposed by Pająk & Ponikiewski (2013). First, quarry sand, coarse aggregate, and fine aggregate were added and mixed for ten minutes, followed by the addition and mixing of cement, marble powder (MP), and dam sediment (DS) for another ten minutes. The next step was to add 60% of the mixed water to the dose of superplasticizer and then leave it to mix for three minutes. Mixing was stopped, and the mixed materials were left to stand and settle for a while. Mixing was then resumed for two minutes with the addition of the remaining water. The shapes of various cast specimens in accordance with the tests envisaged were as follows:

- Cylinders of 11.22 cm in size for compressive strength, 3 specimens for each age, and cubes of 7 .7.7cm for durability tests (acid attack).

After pouring, the samples are covered with a plastic film to prevent water evaporation.

Figure 2 – 7.7.7 cm cubes for durability tests and 11.22 cm cylinders for compressive strength tests

Results and discussion

Characteristics of fresh and cured formulations

Abrams cone slump test

According to NF EN 12350-2 (AFNOR, 2019) of the Abrams cone device, fresh concrete slump values ranging between 640 mm to 720 mm must be obtained, given by measuring the diameter of the concrete, which is more representative than the slump value (see Figure 3).


Figure 3 – Abrams cone slump/spread test

The L-box flow test

The vertical part of the L-box is filled with concrete at one time, NF EN 12350-10 (AFNOR, 2010a). After opening the trapdoor, the concrete flows through standard reinforcement (39 mm between 3 bars φ14), corresponding to heavily reinforced structures,but can be lightened if necessary (58 mm clearance between 2 bars).

For SCC to be accepted, the filling ratio of the L-shaped box (H2/H1 height ratio (see Figure 4) must be greater than 0.8.

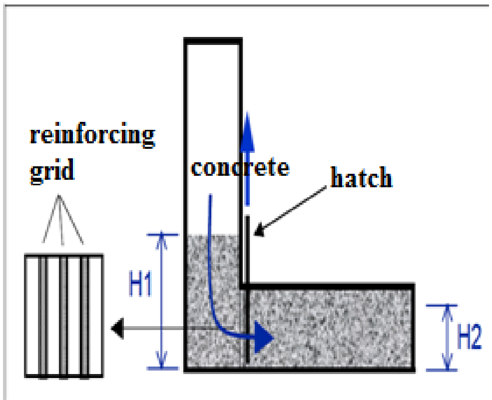

Figure 4 – The L-box test

Flow times can also be measured to assess concrete viscosity. For the first test, this is the time required to reach a spreading diameter of 50 cm, noted t50. For the second one, the time measured (tL) is between the opening of the trapdoor and the moment when the concrete reaches the bottom of the L-box.

The segregation test

Another way of testing the static segregation of SCC is to observe one (or two) specimen(s) of hardened concrete in the direction of casting and observe the distribution of aggregates over the height of the specimen, NF EN 12350-11 (AFNOR, 2010b).

These photographs clearly illustrate that the two concrete formulations presented here are not subject to static segregation. The aggregates are evenly distributed over the entire height of the sawn specimens (cast vertically from the top). This repeated observation for all the SCC compositions studied led to the same conclusion.

Table 4 – Fresh and hardened properties of various formulations

	Settling/ Spreading (cm)	Segregation (%)	L-Box	Theoretical density (kg m-3)	Actual density (kg m-3)	Hardened density (kg m-3)
VC	8,5	--	0.85	2300	2250	2370
SCCMP	68	12.5	0.89	2350	2400	2380
SCCDS	70	13.20	0.88	2320	2350	2385
SCCDSMP	69	12.80	0.86	2330	2345	2382

- Static segregation of SCC: the sieve stability test calculates a segregation rate and deduces whether or not the concrete tested has satisfactory stability. All SCCs have a segregation rate of less than 15%, synonymous with sufficient stability.
- On the dynamic segregation of SCC: the L-box test is used to determine the filling ratio (the height of concrete at the bottom to that at the beginning of the box), which should, in principle, be greater than 0.8.
- Regarding the consistency of vibrated concrete, no conditions had been set beforehand.

SCCDSMP showed the best performance compared with SCCMP and SCCDS. This is due to the physical nature of sediment fillers and marble powder which control compressive strength through a denser matrix and a better dispersion of cement grains (Bonavetti et al, 2001; Diederich et al, 2013).

Determination of uniaxial compressive strength

The specimens used to determine the compressive strength of the various concretes studied were cylindrical test specimens measuring 11cm in diameter and 22cm in height. After demolding, they were stored in a room at 20°C and 95 ± 5% relative humidity until the specified time (7, 14, 21, 28 days).

The press used has a maximum capacity of 3000 kN (Figure 5). Compressive strength was assessed in accordance with standard NF EN 206-1 (AFNOR, 2004): tests were carried out on the most appropriate force scale (600 or 1500 kN), with a loading speed of 0.5 $MPas^{-1}$.

Figure 5 – Press used

Compression tests

The influence of the type of addition on the compressive strengths of concrete at different times is illustrated in Figure 6.

The analysis of the results illustrated in Figure 6 shows the evolution of compressive strength as a function of age for concrete containing different percentages of marble powder and dam sediment preserved in lime-saturated water for 7, 14, 21, and 28 days. It can be seen that the compressive strength of all concretes increases steadily with age and shows no drop.

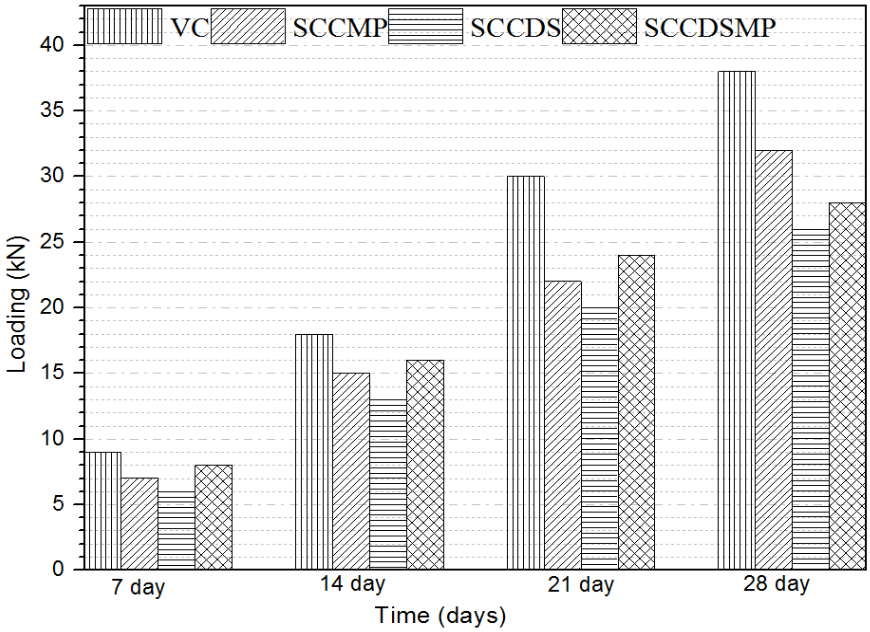

Figure 6 – Influence of the type of addition on the compressive strengths of concretes at different maturities

Figure 6 clearly shows the significant influence of marble powder on compressive strength. The various maturities elaborated with low marble powder show strengths close to those of the control concrete at 7, 14, 21, and 28 days. On the other hand, the concrete made from SCCDS dam sediments had compressive strengths around 15% lower than those of the concrete containing SCCMP marble powder. In comparison, the concrete made from SCCDS dam sediments had compressive strengths around 20% lower than those of SCCMP.

It can be concluded that substituting part of the cement with treated dam sediment provides acceptable compressive strength but lower than the strength given by marble powder, with percentages close to those of the control concrete (without addition). From Figure 6, it can be concluded that the differences between the 28-day strengths and those given for the control concrete are as follows: 30% for dam sediment and 20% for marble powder, Table 5.

Table 5 – Evolution of the ratio of compressive strength to measured strength

Age (days)	VC		SCCMP		SCCDS		SCCDSMP	
i	σi	σi /σ28	σi	σi /σ28	σi	σi /σ28	σi	σi /σ28
7	11	0.25	9.50	0.25	8.00	0.25	11.5	0.27
14	20.60	0.47	16.20	0.43	14.50	0.45	18	0.45
21	31	0.71	24	0.63	22	0.69	26	0.64
28	43.46	1.00	37.61	1.00	31.81	1.00	40.11	1.00

To better visualize all the variations in the rate of evolution of compressive strengths, we study the ratio:

- D_i /D_{28} : (i = 7 - 28 days), Table 5.

For a 7-day duration, we observed an evolution of between 25% for SCCMP and SCCDS, which is equal to that of VC vibrated concrete, but we observed an evolution of 30% for SCCDS, see Figure 6.

At 14 days, an increase of around 47% is obtained for VC vibrated concrete, while SCCMP and SCCDS self-compacting concretes show an increase of around 43% to 45%.

At 14 to 28 days, the difference is more significant, with VC vibrated concrete showing an increase in strength of 53%, while SCCMP and SCCDS self-placing concretes show increases ranging from 55 to 57%.

Self-compacting concrete containing dam sediment develops strength comparable to self-compacting concrete containing marble powder at 21 days without any noticeable reduction.

SCCMP self-compacting concrete develops strength comparable to VC vibrated concrete at 28 days.

The properties of the aggregates used to make concrete mixes are presented in Table 1 and Figure 1. Much sediment was supplied from the Fergoug dam site in northwest Algeria. It was prepared using two processes: the first involves extracting it from the dam and placing it in a kiln at 450°C to remove impurities and organic matter, while the second process involves crushing and sieving under a two-millimeter sieve. Its dimensions vary from 1 mm to 2 mm (Figure 1).

Testing the durability of concretes in acid solutions

To evaluate the durability of hardened concretes exposed to acid solutions and to highlight the influence of acids on different compositions

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of different concretes, we monitored the variation in the mass of the cubic test specimens (70. 70. 70) mm^3 in the following solutions: 5% hydrochloric acid (HCl); 5% sulfuric acid (H_2SO_4);5% sodium sulfate (Na_2SO_4).

Mass variation was monitored on the test tubes immersed in various acid solutions (Figures 7 and 8) in accordance with ASTM C267, using a 0.01 g precision balance (Figure 9).

5%HCl **5% H_2SO_4** **5%Na_2So_4**

Figure 7 – Cubic test tubes immersed in acid solutions

Once the test tubes have been removed from their storage medium, they are cleaned 3 times with fresh water and left to dry for 30 min.

In order to better characterize the progress of the degradation of concretes with different additions by the attack of acid solutions and sulfate, we opted to quantify the loss of the mass of these concretes over time for a period of 1 to 28 days.

5%HCl **5% H_2SO_4** **5%Na_2So_4**

Figure 8 – Condition of the cubic specimens after acid etching

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Figure 9 – Precision balance test

Influence of hydrochloric acid solution (5% HCl)

After 24 hours of immersion in a hydrochloric acid solution, VC vibrated concrete, SCCMP, and SCCDS self-placing concretes show the same strength levels (ML = 1.59 to 1.77%), see Figure 10. From 7 days onwards, the attack progresses over time, particularly in the case of vibrated concrete VC, with a mass loss of 49.36% at 28 days. At 28 days of attack, the mass losses recorded are significant, amounting to 40.74% for SCCMP marble powder concrete and 38.78% for SCCDS dam sediment concrete.

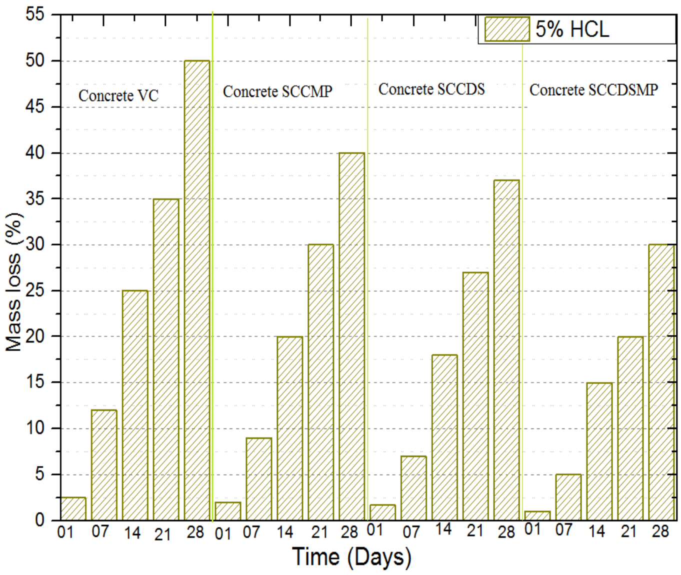

Figure 10 – Influence of the acid solution HCL on the mass loss of concrete from different additions at different times

Influence of the sulfuric acid solution (5% H_2SO_4)

The self-placing concretes of the two additions (marble powder, dam sediment) show very good resistance to attack by the sulfuric acid solution after 24 hours since mass losses do not exceed 0.11% (Figure 11). This resistance tends to weaken over time, giving rise to mass losses of 1.30% for SCCMP marble powder concretes, 0.29% for SCCDS dam sediment concretes, and 0.25% after 7 days, while the rates recorded at 21 days are 3.91% and 1.09%, respectively. After a 28-day attack, the SCCDS sediment dam concretes showed better strength (ML = 1.11%) than the SCCMP marble powder concretes (ML = 5.34%), with high mass loss rates for the VC vibrated concretes of 17.50% at 28 days. (ML: mass loss).

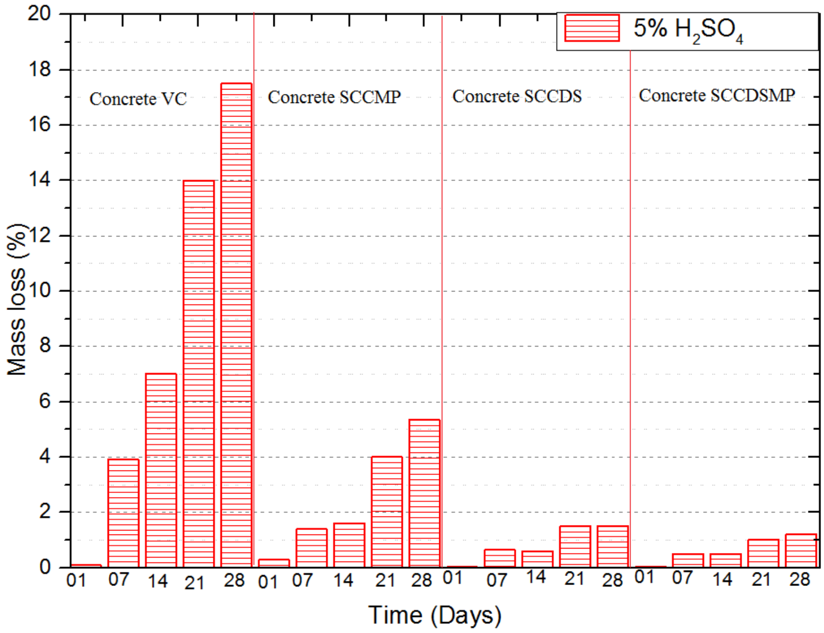

Figure 11 – Influence of the acid solution H_2SO_4 on the mass loss of concrete from different additions at different times

Influence of the sodium sulfate solution (5% Na_2SO_4)

Generally speaking, concretes with 3 additions (SCCMP and SCCDS) show almost the same resistance to attack by the sodium sulfate solution at each maturity. The mass losses recorded are very close at each maturity and are effectively (- 0.09 to - 0.1%) at 1 day, (0.65 to 0.77%) at 7 days, (1.96 to 2.46%) at 21 days and (2.60 to 3.20%) at 28 days (Figure 12).

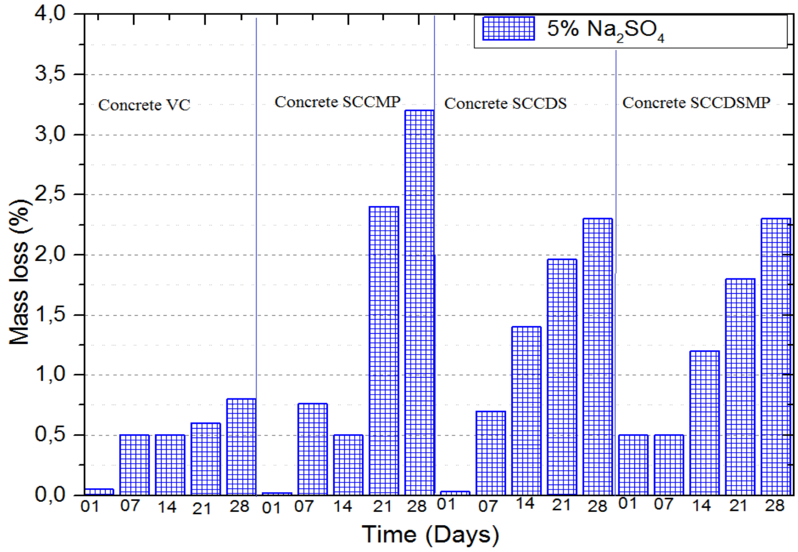

Figure 12 – Influence of the sodium sulfate solution Na_2SO_4 on the mass loss of concrete from different additions at different times

At 28 days of immersion in the sulfate solution, the VC vibrated concrete showed less mass loss than the self-placing concretes with the 3 additions (marble powder and dammed sediment). This phenomenon is probably attributed to the filling of vacant voids in the pores of vibrated concrete exposed to the sulfate solution by secondary gypsum and ettringite, resulting in lower mass loss than the other concrete.

The mass losses of concretes made with various additions are more or less affected by the nature of the acid solution, with the most aggressive being (HCl), followed by (H_2SO_4), and finally (Na_2SO_4).

Concrete is more resistant to sulfuric acid attacks but shows no signs of resistance to hydrochloric acid solutions. This difference in resistance may be due to the high proportion of $CaCO_3$ and CaO in the gaskets and C_3S in the cement (47.15%), which, after hydration, gives rise to a large quantity of portlandite. The latter, in turn, reacts with acid (HCl) to form large amounts of calcium chloride salt. Given the solubility of this salt, porosity tends to increase, facilitating the penetration of the aggressive medium into the cementitious matrix and consequent weakness in strength.

Concretes made with different additives are more or less affected by sulfate (Na_2SO_4). By comparison, concrete made without admixtures shows good resistance to the sulfatic acid solution, compared with the attack of other solutions. This resistance can be attributed to the formation of expansive secondary ettringite, which covers the surface layer of the cementitious matrix and thus limits the inward progress of acidic degradation.

Visual examination

Figure 13 shows the condition of the cubes of different concretes at the age of 28 days and after 28 days of immersion in lime-saturated water. Visual examination reveals no signs of degradation.

The photos shown in Figure 13 concern the SCCDSMP concrete sample formed from dam sediments, marble powder and cement, and submerged in the solutions over a period of 28 days.

Visual analysis was carried out to assess the obvious signs of external deterioration of the concrete specimens, such as weathering, cracking, and softening, following storage in different media.

Figure 13 – Condition of the cubic specimens of SCCDSMP concrete after etching at 28 days

Figure 13 shows the results of changes and deformations in the concrete formed from dam deposits, marble powder, and cement in the following ratios: 30 %, 20 %, and 50 %. The concrete samples immersed in HCl acid and H_2SO_4 acid showed considerable deformation; a thin layer of yellowish rust on the surface differed from the initial color of the cementitious matrix and appeared to be due to the presence of weakly crystalline Fe_2O_3 iron hydroxide.

The surface of the concrete is thoroughly cleaned, with a significant loosening of the sand grains. The solubility of the salt formed, $Ca(NO_3)_2.2H_2O$, after the reaction of HCl with the portlandite $Ca(OH)_2$ released during cement hydration and its extensive external filtration with progressive decalcification of the C-S-H, led to significant mass losses. The samples immersed in Na_2SO_4 acid appear to have no effect or change.

In HCl, a significant reduction in the volume of concrete samples was observed. As a general rule, concrete surfaces undergo more pronounced deterioration in HCl than in H_2SO_4. HCl is more aggressive than H_2SO_4. The results of mass loss tests confirmed these observations.

Conclusions

The experimental results of this study which consisted of monitoring the evolution of the mechanical strengths (compression) of concrete made with cement and mineral additions (marble powder, Fergoug dam sediment), quantified by the chemical attack of acid solutions (hydrochloric, sulfuric, and sulfatic with a concentration of 5%), and the relative mass variations or mass losses, lead to the following conclusions:

The various maturities produced with marble powder have strengths close to those of the control concrete at 28 days (R_C28= 37.61 MPa). On the other hand, the concrete made with SCCFS dam sediment has a compressive strength 15% lower (R_C28= 31.81 MPa) than that of the concrete made with SCCMP marble powder, which is 20% lower (R_C28= 30.09 MPa). This difference in strength may be due to the high proportion of marble powder contained in the concrete, which is due to the consumption of Portlandite (CH) produced as a result of cement hydration. This reaction produces additional C-S-H gels that contribute to the improved strength of marble concretes. On the other hand, the strength of concrete based on dam sediments is always lower than that of the control concrete, which can be explained by the activity and percentages of fines contained in these mineral additions.

The mass losses of concretes made with various additions are more or less affected by the nature of the acid solution, with the most aggressive HCl, followed by H_2SO_4, and finally Na_2SO_4.

SCCDS dam sediment concretes are more resistant (ML = 38.78%) to attack by the hydrochloric acid solution than marble powder concretes (ML = 40.74%);

Concrete made without additives shows good resistance to the sulfuric acid solution (ML = 0.9%). This resistance can be attributed to the formation of expansive secondary ettringite which covers the surface layer of the cementitious matrix and, therefore, limits the inward progress of acidic degradation.

Concrete made from marble powder and dam sediments (SCCDSMP) gave positive results, similar to those of concrete made from quartz powder (VC).

References

-ACI Committee 237. 2007. 237R-07: Self-Consolidating Concrete. *ACI American Concrete Institute*, January 4 [online]. Available at: https://www.concrete.org/publications/internationalconcreteabstractsportal/m/details/id/18605?gad_source=1&gclid=CjwKCAiA6aW6BhBqEiwA6KzDc9agd-Q_3KkIxCQYzmj-fIVB06rtwGVxavJ-pEILHf1cHJYAaPr6tRoCdCAQAvD_BwE [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 1991. *NF P94-054: Sols : reconnaissances et essais - Détermination de la masse volumique des particules solides des sols - Méthode du pycnomètre à eau* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-p94054/sols-reconnaissance-et-essais-determination-de-la-masse-volumique-des-parti/fa020767/11077 [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 1992. *NF P94-057: Sols : reconnaissance et essais - Analyse granulométrique des sols - Méthode par sédimentation* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-p94057/sols-reconnaissance-et-essais-analyse-granulometrique-des-sols-methode-par-/fa020768/11074 [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 1993. *NF P94-051: Sols : reconnaissance et essais - Détermination des limites d'Atterberg - Limite de liquidité à la coupelle - Limite de plasticité au rouleau* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-p94051/sols-reconnaissance-et-essais-determination-des-limites-datterberg-limite-d/fa020765/11080 [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 1996. *NF P94-056: Sols : reconnaissance et essais - Analyse granulométrique - Méthode par tamisage à sec après lavage* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-p94056/sols-reconnaissance-et-essais-analyse-granulometrique-methode-par-tamisage-/fa026936/11075 [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 1998a. *NF EN 1744-1: Essais pour déterminer les propriétés chimiques des granulats - Partie 1 : analyse chimique* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-en-17441/essais-pour-determiner-les-proprietes-chimiques-des-granulats-partie-1-anal/fa039721/62422 [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 1998b. *NF P94-068: Sols : reconnaissance et essais - Mesure de la capacité d'adsorption de bleu de méthylène d'un sol ou d'un matériau rocheux - Détermination de la valeur de bleu de méthylène d'un sol ou d'un matériau rocheux par l'essai à la tache* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-p94068/sols-reconnaissance-et-essais-mesure-de-la-capacite-dadsorption-de-bleu-de-/fa043689/394 [Accessed: 29 March 2024].

-AFNOR Association française de normalisation. 2004. *NF EN 206-1: Concrete - Part 1 : specification, performance, production and conformity* [online]. Available at: https://www.boutique.afnor.org/en-gb/standard/nf-en-2061/concrete-part-1-specification-performance-production-and-conformity/fa125184/22922 [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 2010a. *NF EN 12350-10: Essai pour béton frais - Partie 10 : béton auto-plaçant - Essai à la boîte en L* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-en-1235010/essai-pour-beton-frais-partie-10-beton-autoplacant-essai-a-la-boite-en-l/fa165666/36401 [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 2010b. *NF EN 12350-11: Essai pour béton frais - Partie 11 : béton auto-plaçant - Essai de stabilité au tamis* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-en-1235011/essai-pour-beton-frais-partie-11-beton-autoplacant-essai-de-stabilite-au-ta/fa165665/36326 [Accessed: 12 April 2024].

-AFNOR Association française de normalisation. 2019. *NF EN 12350-2: Essais pour béton frais - Partie 2 : essai d'affaissement* [online]. Available at: https://www.boutique.afnor.org/fr-fr/norme/nf-en-123502/essais-pour-beton-frais-partie-2-essai-daffaissement/fa190558/83431 [Accessed: 12 April 2024].

Bassuoni, M.T. & Nehdi, M.L. 2007. Resistance of self-consolidating concrete to sulfuric acid attack with consecutive pH reduction. *Cement and Concrete Research*, 37(7), pp.1070-1084. Available at: https://doi.org/10.1016/j.cemconres.2007.04.014.

Bonavetti, V.L., Rahhal, V.F. & Irassar, E.F. 2001. Studies on the carboaluminate formation in limestone filler-blended cements. *Cement and Concrete Research*, 31(6), pp.853-859. Available at: https://doi.org/10.1016/S0008-8846(01)00491-4.

Denis, P.E. 2008. *Optimisation du béton autoplaçant : mise en place en laboratoire et sur chantier*. Master’s Final Project. Leeds: École des Mines de Saint-Étienne.

Diederich, P., Mouret, M. & Ponchon, F. 2013. Simple tools for achieving self-compacting ability of concrete according to the nature of the limestone filler. *Construction and Building Materials*, 48, pp.840-852. Available at: https://doi.org/10.1016/j.conbuildmat.2013.07.071.

Hammadi, L., Ponton, A. & Belhadri, M. 2011. Rheological study and valorization of waste sludge from wastewater treatment plants in the dredging operation of hydraulic dams. *Energy Procedia*, 6, pp.302-309. Available at: https://doi.org/10.1016/j.egypro.2011.05.034.

Labiod-Aloui, Z., Trouzine, H., Ghembaza, M.S., Nouioua, T. & Sebaibi, Y. 2014. Experimental investigation of mixtures of bentonite and dredged sediments from Chorfa dam in Algeria. *Turkish Journal of Earth Sciences*, 23(3), pp.330-338. Available at: https://doi.org/10.3906/yer-1302-13.

Muhedin, D.A. & Ibrahim, R.K. 2023. Effect of waste glass powder as partial replacement of cement & sand in concrete. *Case Studies in Construction Materials*, 19, e02512. Available at: https://doi.org/10.1016/j.cscm.2023.e02512.

Pająk, M. & Ponikiewski, T. 2013. Flexural behavior of self-compacting concrete reinforced with different types of steel fibers. *Construction and Building*

Materials, 47, pp.397-408. Available at: https://doi.org/10.1016/j.conbuildmat.2013.05.072.

Ranatunga, K.S., del Rey Castillo, E. & Toma, C.L. 2023. Evaluation of the optimal concrete mix design with coconut shell ash as a partial cement replacement. *Construction and Building Materials*, 401, art.number:132978. Available at: https://doi.org/10.1016/j.conbuildmat.2023.132978.

Scherer, C., de Lima, L.F. & Zorzi, J.E. 2023. Effect of partial replacement of cement by fine powders on the corrosion resistance of concrete. *Construction and Building Materials*, 401, art.number:132982. Available at: https://doi.org/10.1016/j.conbuildmat.2023.132982.

Sellaf, H. & Balegh, B. 2023. Effect Of Waste Marble Powder On The Properties Of White Mortar Made From Tuff. *Journal of New Technology and Materials*, 13(1), pp.25-32 [online]. Available at: https://www.asjp.cerist.dz/index.php/en/article/227651 [Accessed: 17 October 2024].

Sellaf, H., Balegh, B. & Bkhiti, M. 2023. The Assessment and Treatment of Dredged Sediments and Limestone Tuff Using Waste Ceramic with Low-Cement. *Advanced Engineering Forum*, 48, pp.45-58. Available at: https://doi.org/10.4028/p-2j4d93.

Thunuguntla, C.S. & Gunneswara Rao, T.D. 2018. Effect of mix design parameters on mechanical and durability properties of alkali activated slag concrete. *Construction and Building Materials*, 193, pp.173-188. Available at: https://doi.org/10.1016/j.conbuildmat.2018.10.189.

Influencia de la adición de sedimentos en el comportamiento mecánico del hormigón reforzado con fibras en ambientes agresivos

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CAMPO: materiales
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: El uso de materiales cementantes suplementarios (SCM) en la construcción ha ganado popularidad debido a su capacidad para mejorar las propiedades mecánicas y la sostenibilidad ambiental del hormigón. Este estudio tuvo como objetivo investigar el potencial de utilizar materiales de desecho, específicamente polvo de mármol (MP) y sedimento de presa (DS), como reemplazos parciales del cemento en el hormigón autocompactante (SCC). Los objetivos principales fueron reciclar estos materiales de desecho y evaluar la durabilidad y la resistencia del SCC expuesto a entornos químicos agresivos.

Métodos: En este estudio, el cemento fue reemplazado parcialmente por 40% MP, 40% DS y una combinación de 20% MP y 20% DS. El desempeño de dicho concreto fue evaluado a través de pruebas de resistencia a la compresión realizadas durante 28 días. La durabilidad fue evaluada exponiendo el concreto a ataques químicos de soluciones de ácido clorhídrico (HCl), ácido sulfúrico (H_2SO_4) y sulfato de sodio (Na_2SO_4). También se midió la pérdida de masa debido a estos ataques químicos.

Resultados: El hormigón que incorpora MP presentó resistencias a la compresión similares a las del hormigón control, alcanzando 37,61 MPa a los 28 días. El hormigón con DS exhibió menor resistencia (31,81 MPa) y mostró mayor resistencia al HCl (ML = 38,78%) en comparación con el hormigón MP (ML = 40,74%). Además, todas las muestras de hormigón exhibieron buena resistencia al ácido sulfúrico debido a la formación de etringita expansiva que protegió al hormigón de una mayor degradación.

Conclusión: Los resultados indicaron que tanto el polvo de mármol como el sedimento de presa son materiales complementarios viables para mejorar las propiedades mecánicas y la durabilidad del hormigón autocontenible. El hormigón con polvo de mármol mostró una resistencia superior, mientras que el sedimento de presa contribuyó a mejorar la resistencia a los ácidos. La combinación de estos materiales ofrece una solución sostenible para el hormigón expuesto a entornos agresivos.

Palabras claves: hormigón (SCC), sedimento, polvo de mármol, fibra, pérdida de masa, mecánico, ambiente agresivo.

Влияние добавок на седиментационную устойчивость и механические свойства фибробетона в агрессивных средах

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РУБРИКА ГРНТИ: 81.09.00 Материаловедение
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Использование заменителей цементных материалов (ЗЦМ) в строительстве приобрело популярность благодаря их способности улучшать механические свойства и экологическую устойчивость бетона. Целью данного исследования было изучение потенциала использования отходов, в частности, мраморной крошки (МР) и отложений плотины (ОП) в качестве частичной замены цемента в самоуплотняющемся бетоне (СУБ). Основными задачами были утилизация этих отходов и оценка долговечности и прочности ЗЦМ, подверженных воздействию агрессивных химических сред.

Методы: В данном исследовании цемент был частично заменен на 40% МК, 40% ОП и смеси из 20% МК и 20% ОП. Свойства полученного бетона испытаны на прочность при сжатии в течение 28 дней. Прочность бетона оценивалась путем воздействия растворов соляной кислоты (HCl), серной кислоты (H_2SO_4) и сульфата натрия (Na_2SO_4). Также была измерена потеря массы в результате этих химических воздействий.

Результаты: Бетон, содержащий МК, показал прочность на сжатие, аналогичную прочности контрольного бетона, *достигнув 37,61 МПа через 28 дней. Бетон с ОП обладал более низкой прочностью (31,81 МПа) и более высокой стойкостью к HCl (ML = 38,78%) по сравнению с бетоном с МК (ML = 40,74%). Помимо того, все образцы бетона показали высокую стойкость к воздействию серной кислоты благодаря образованию обширного эттрингита, защищавшего бетон от дальнейшего разрушения.*

Вывод: Результаты показали, что как мраморная крошка, так и отложения плотины являются полезными материалами-заменителями для улучшения механических свойств и долговечности бетона. Бетон с мраморной крошкой показал превосходную прочность, а отложения плотины способствовали повышению кислотостойкости. Сочетание этих материалов обеспечивает надежное решение для бетона, подверженного воздействию агрессивных сред.

Ключевые слова: бетон (СУБ), добавки, мраморная крошка, волокно, потеря массы, механическая обработка, агрессивная среда.

Утицај седиментних адитива на механичко понашање бетона армираног влакнима у агресивним срединама

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ОБЛАСТ: материјали
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Материјали који замењују цемент (Supplementary Cementitious Materials, SCM) све чешће се додају бетону у градитељству због своје способности да побољшавају механичка својства бетона, као и због одрживости животне средине. У овој студији испитане су могућности коришћења отпадних материјала – мермерног праха (МП) и седимената насталих при грађењу брана (ДС), као делимичне замене за цемент у самозбијајућем бетону (Self-compacting Concrete, SCC). Примарни циљеви били су рециклирање ових отпадних материјала и процена трајности и чврстоће самозбијајућег бетона изложеног хемијски агресивном окружењу.

Методе: У овом истраживању цемент је био делимично замењен са 40% МП, 40% ДС и комбинацијом 20% МП и 20% ДС. Перформансе бетона су испитане тестовима чврстоће при притиску током 28 дана. Трајност је испитивана излагањем бетона хемијској агресији раствора хлороводоничне киселине (HCl), сумпорне киселине (H_2SO_4) као и натријум сулфата (Na_2SO_4). Такође, вршено је мерење губитка масе услед овог излагања хемикалијама.

Резултати: Бетон са садржајем МП показао је чврстоћу при притиску сличну оној коју има контролни бетон, постижући 37,61 MPa за 28 дана, док је бетон са ДС имао мању чврстоћу (31,81 MPa), а већу отпорност на хлороводоничну киселину (ML=38,78%) у поређењу са бетоном са МП (ML=40,74%). При томе су сви узорци бетона имали добру отпорност на сумпорну киселину због формирања експанзивног етрингита који штити бетон од даље деградације.

Закључак: Резултати су указали да су и мермерни прах и седимент брана могући као допунски материјали за побољшавање механичких особина и трајности самозбијајућег бетона. Показано је да бетон са мермерним прахом има супериорну чврстоћу, док је седимент добијен грађењем брана допринео побољшању отпорности на киселине. Комбинација ових материјала нуди одрживо решење за бетоне изложене агресивним срединама.

Кључне речи: бетон (SCC), седимент, мермерни прах, влакно, губитак масе, механичка обрада, агресивна средина.

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