

Transport properties of blended cement based on dredged sediment and shells

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Abstract

This paper reports an experimental study carried out to investigate the influence of dredged sediments and shell powders on the transport properties of mortar. Blend based on the combination of marine by-products was used to replace a part of Portland cement, after thermal treatment. Cylindrical mortars and pastes were cast with water to binder ratio of 0.5 and 0.4, respectively. Control specimens were also cast. After 28 days of curing in water, the apparent porosity, the gas permeability, the chloride diffusion and accelerated carbonation was investigated. The results showed that the combination of dredged sediment and shell powder provides a positive effect on the transport properties. Besides, mortars containing 33% by weight of blend showed low gas permeability than that of the control mortar even apparent porosity is higher. In addition, the resistance to the chloride ingress is more pronounced for mortars with sediment:shell blend. The carbonation thickness is related to the carbonation age and replacement level. This blend proved better transport properties by the filler effect. Copyright © 2017 VBRI Press.

Keywords: Dredged sediment, shells, permeability, chloride ingress, transport properties.

Introduction

The progressing of concrete structure faced with transport properties problems which causing a negative impact on the construction lifespan and the maintenance fees especially for porous and non-homogeneous structures [1]. Researchers try to overcome these weaknesses and focused on the improvement of concrete transport properties. At the same time, a huge amount of industrial waste and by-product are creating environmental matters [2]. Therefore, it is essential to find an alternative use to reduce wastes that are dumped.

In recent decades, many research groups have established the use of supplementary cementitious materials that can improve the various properties of concrete and contribute to the economy in construction costs. Major transport properties of concrete are permeation, diffusion, sorption and absorption through which the aggressive media penetrate into the bulk of concrete and may cause gradual degradation [3, 4]. The permeability of concrete is related to the pore connectivity which is affected by water to binder ratio, mineral additives, curing conditions, activity of mineral admixture and the penetration condition such as penetration time and chemistry of penetration media [4]. A lower permeability reduces the ingress of aggressive media.

Several studies [5, 6] showed that the addition of mineral admixtures improved the permeability of concrete because of their denser pore structure. For concrete based on Portland cement, the degradation caused by an external chemical attack which produces the precipitation of expansive compounds and/or induces the de-passivation

of steel and initiates the corrosion of the reinforcement bars [7-9]. Chloride ingress is on the main causes for the durability of reinforced concrete structure. The chloride binding in hydrated compounds can drop the chloride concentration in the pore solution. Hence, it can retard the chloride ingress, and decrease the corrosion risk [10]. Frias et al [11] mentioned that the high NaCl content in the pore solution leads to the formation of hydrated aluminates of layered structure which are transformed into Friedel's salt, thus, it decrease the porosity of the material.

This experimental study investigates the beneficial use of marine by-products as an alternative material for cement production. It addresses the role of dredged sediments and oyster shell powder as a cement replacement in improving the transport and durability properties of mortars. First of all, the raw materials are characterized using several techniques to define their chemical and physical properties. Secondly, calcinations of raw materials are performed in order to eliminate all organic matters and activate the clays. Six blends are designed to replace Portland cement (8%, 16% and 33% by weight). The effect of treated marine by-products on apparent porosity, gas permeability, chloride diffusion and accelerated carbonation was evaluated.

Experimental

Materials

Two kinds of marine co-products were used as one to Portland cement replacement. Physical and chemical

properties of Portland cement classified as CEM I and raw materials are presented in **Table 1**.

Table 1. Physical and chemical properties of materials.

	CEM I	Dredged sediment	Shell powder
SiO ₂ (%)	21.4	37.53	-
CaO (%)	64.5	14.86	48
Fe ₂ O ₃ (%)	4.68	3.06	-
Al ₂ O ₃ (%)	3.61	3.53	-
Na ₂ O (%)	0.17	1.14	0.3
MgO (%)	0.62	1.57	0.5
K ₂ O (%)	0.6	0.57	-
SO ₃ (%)	2.67	0.72	-
Salinity (g.L ⁻¹)	-	0.5	0.8
d ₅₀ (µm)	11	25	82
Loss on ignition (%)	1.2	37	51

The replacement binders were prepared by mixing dredged sediments and shell powder with a ratio of 1:2 by weight and subsequently partial replacement of CEM I cement by 8%, 16% and 33% of the blend. Previously, and for the organic matter combustion and the clays activation, a controlled calcination of raw materials at 650°C and 850°C was performed [12]. The SS6 and SS8 binders are respectively the sediment:shell powder blend calcined at 650°C and 850°C. Mineralogical analysis of treated binders appeared in **Fig. 1**. The median size of SS6 and SS8 binders were 5.9 and 7.6 µm, respectively.

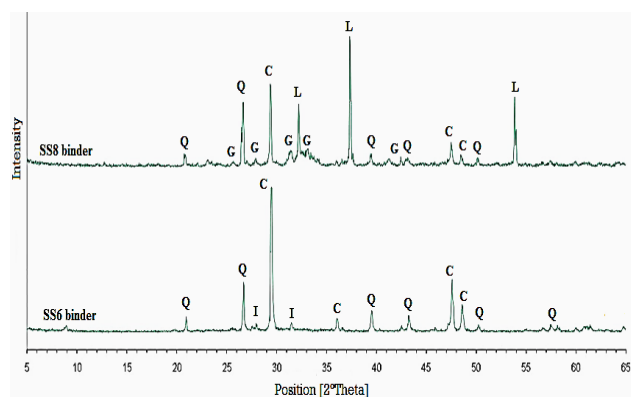


Fig. 1. Mineralogical analysis of sediment: shell powder blend calcined at 650°C (SS6) and 850°C (SS8), C: calcite; G: gehlenite; I: illite; L: CaO; Q: quartz.

Test procedures

The mix proportions for cylindrical samples are presented

Table 2. Mixing proportions of different specimens.

Replacement level	Paste specimens			Mortar specimens			
	CEM I (g)	Binder (g)	Water (g)	CEM I (g)	Sand (g)	Binder (g)	Water (g)
0 %	210	-	84	225	675	-	112
8 %	193	17	84	207	675	18	112
16 %	176	34	84	189	675	36	112
33 %	141	70	84	150	675	75	112

in **Table 2** in which water to binder (w/b) ratio of 0.4 and 0.5 were used for paste and mortar specimens,

respectively. The size of paste specimens was Ø 35mm × h 40mm. The size of mortar specimens was Ø 40mm × h 60mm. After one day of casting in plastic molds, samples were demoulded and cured in water at 20 ± 2°C for 28 days.

At the end of the 28th day, apparent porosity (A.P) was carried out on mortar cylinders. It consists in measuring the mass of each specimen by weighing it in air and then under water using a hydrostatic weighing. After, the specimens are dried at 105°C until mass stabilization and then the (A.P) is determined according to AFREM recommendation [13]. Gas permeability (G.P) test was conducted using Helium gas in which a constant pressure was applied between the two extremities of the cylindrical mortars. Cylindrical pastes were covered with an adhesive aluminum leaf on both areas to allow a unidirectional carbonation. The accelerated carbonation test was performed in a chamber under the conditions of temperature (35 ± 3°C), relative humidity (70 ± 5%), and 20% carbon dioxide. Then, the carbonated specimens were taken out of the chamber and maintained in desiccator at room temperature until the measurement tests. The carbonation thickness was measured up to 1 and 4 weeks after spitting-tensile of specimens. For chloride diffusion experiment, mortars saturated under vacuum with solution NaOH 0.1M and held for 24 hours.

Then, they were coated with a waterproof resin except the area whereby chloride ingress will occur. The specimens were placed in a container with supports in the bottom to lift samples from the base of the container allowing the free chloride ingress. Specimens were stored in CaCl solution with 0.5M concentration for 8 months at room temperature. At the end of the emersion period, mortar cylinders were vacuum-dried in a desiccator in the presence of silica gel at room temperature for 2 days. Free and bound chloride concentrations at each depth were measured by cutting cylindrical specimens into slices of 5 mm from immersed area and grinding into powder. After these, grinding materials were then tested according to the GrandDuBé protocol [14].

Results and discussion

Physical properties

The **Fig. 2** presents the evolution of apparent porosity (A.P) as a function of gas permeability (G.P) for control and substituted mortars.

It is observed that the (A.P) increases with increasing replacement level of additions. For the control mortar, the

(A.P) is on average 17.4%. The 33% substituted mortar goes up to 18.9% and 19.4% respectively for SS6 and SS8 binders. The same evolution was observed on mortars with treated sediment aggregates used as sand substitution [15]. During the manufacturing of mortars, it is observed that samples with a high amount of additions were more difficult to be cast into the mold, while the mixing water was limited (water-to-solid ratio of 0.5) and consumed in part by additions, thus, high air bubble training. The (G.P) of substituted mortars increases slightly with the replacement level but it remains very lower than that of the control mortar whatever the substitution ratio which is indicative of a fine microstructure and low porous network connectivity [3, 16].

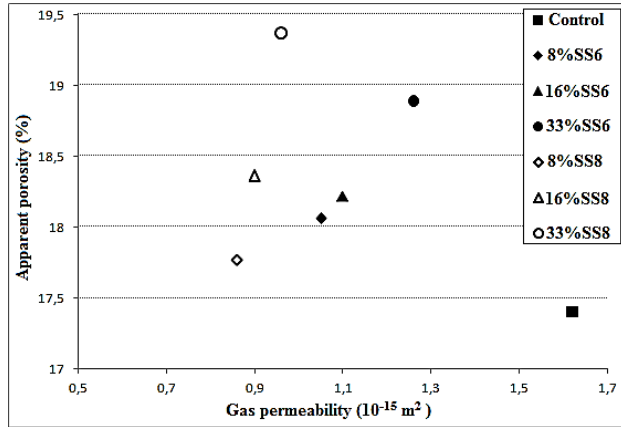


Fig. 2. Apparent porosity (A.P) as a function of gas permeability (G.P) for control mortar and substituted mortars increasing substitution ratio.

The effect of the use of sediments and shells is significant: the (G.P) is weaker while the (A.P) increases with increasing the replacement level. It is attributable to the filler effect of fine particles that induces a significant porous network modification of the mortar.

Chloride diffusion

The free and bound chloride concentration profiles obtained after 8 months of immersion in a saline solution are respectively presented in Fig. 3.

It is clearly seen that the penetration of chloride does not depend on the replacement level or heat treatment. The resistance to chloride penetration of substituted mortars is higher than that of the control mortar. The use of treated sediment and shells enhances the resistance to chloride penetration of mortar. The free chloride profiles for substituted mortars (Fig. 3-a and b) are lower than that of the control and decrease with depth; this is understood as a better property of transport. The fine particles of used addition provide a denser packing to the mortar by applying a filler effect and refine the porous microstructure which decreases the porous network connectivity and contributes to reducing the permeability [11, 15].

At 0.5 mm from the surface, the bound chloride concentrations are higher in the case of the control mortar. A large difference of 40% and 57% respectively for 33% SS6 (Fig. 3-c) and 8% SS8 (Fig. 3-d) mortars, which showed the high bound chloride concentrations at the

surface for the substituted mortars, compared to the control mortar. This difference is may be attributed to the filler effect of fine particles which decrease the pore size at the surface of the substituted mortars compared to the CEM I mortar. It is observed [17] that the CEM I mortar has a large pore size at the surface which chlorides could be bounded. A considerable decrease of binding chloride is observed for the control mortar throughout their depth. In the other hand, whatever the replacement level and temperature treatment, binding chlorides decrease moderately over the depth for substituted mortars. After 21 mm from the surface, the binding chloride concentrations for mortars with sediments and shells (Fig. 3-c and d) are higher than that of ordinary mortar which can be corresponded to the chlorides initially exist in the addition materials [18].

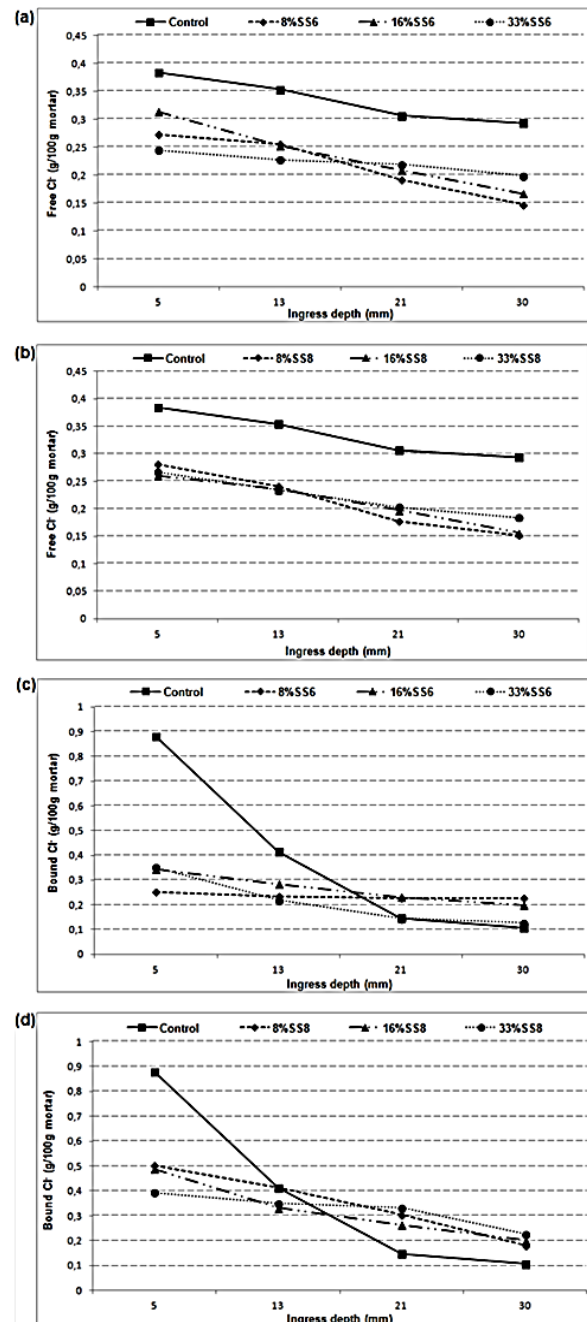


Fig. 3. Free (a and b) and bound (c and d) chloride profiles for mortars.

Carbonation thickness

After one and four weeks, carbonation thickness has been measured with a colored indicator of pH such as phenolphthalein by spraying 1% phenolphthalein–alcohol liquid on the fractured specimen surface as shown in Fig. 4, and the thickness of discolored portion was measured. The results can be seen in Fig. 5.

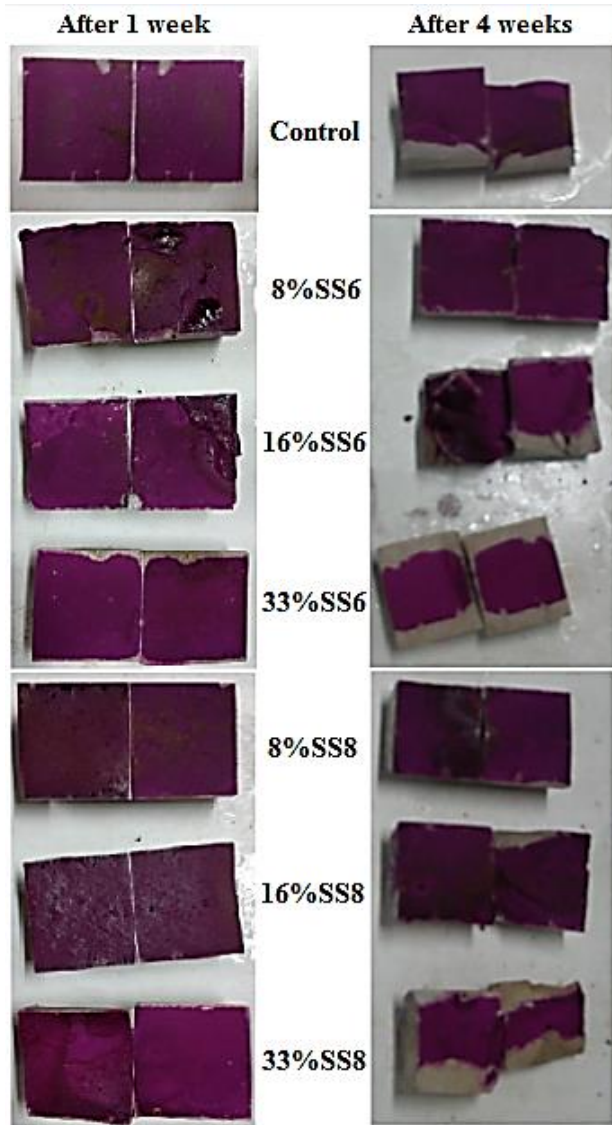


Fig. 4. Macroscopic images of phenolphthalein-stained cross-sections after one and four weeks.

For all samples, results show that carbonated thicknesses are not defined after one week of accelerated carbonation. At this age, a net zone of pink color can be observed in all samples. The discolored zone was significant after four weeks. The carbonation resistance of 8% SS6, 8% SS8, and 16% SS8 pastes becomes six times higher than ordinary paste. The sample 16%SS6 had the same carbonated thickness than the control. The samples with 33% of binders showed a significant colored zone compared to the colorless zone. According to the results, the carbonation thickness increased with increasing carbonation ages and the replacement level [19, 20]. This tendency is in agreement with the results obtained by

Yang *et al.* [19] who reported that the effect of substitution ratio of crushed oyster shells on carbonation characteristics of concrete lead the carbonated thickness with increasing substitution ratio of oyster shells. Concretes elaborated with 25% and 30% of fly ash had a lower carbonation resistance [20]. It can be explained by the fact that a high (A.P) of samples with high addition amount (33% by weight) led to the CO₂ penetration.

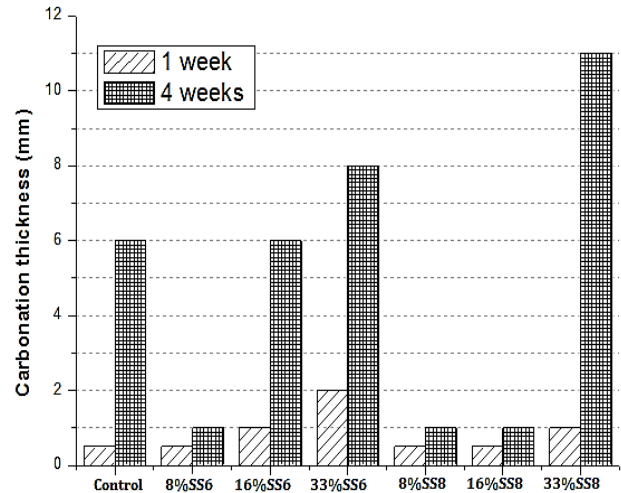


Fig. 5. Carbonation evolution for different pastes.

Conclusion

The experimental studies Showed that the use of dredged sediment:shell powder blends lead to increase the apparent porosity of mortars by increasing the replacement level, while the gas permeability still far lower than that of the control mortar which is indicative of a fine microstructure and low porous network connectivity. This effect is related to the filler effect of fine particles of sediment and shell powder that induces a significant porous network modification of substituted mortars. The free chloride ingress does not depend on the replacement level of addition. The use of sediment:shell blends decreases the chloride ingress of mortars compared to the control. The resistance to chloride penetration of substituted mortars increases with depth. This is due to the fact that the fine particles provide a denser packing by carrying a filler effect and refinement of the porous microstructure which leads a low permeability of free chlorides. A large bound chloride concentration was obtained at the surface of the control mortar. The pore size at the surface of substituted mortars may be reduced by the filler effect which leads the low bound chloride compared to the control. The bound chloride concentration decreases significantly for the control and moderately for the substituted mortars through their depth. One week of accelerated carbonation shows no results of carbonated thickness. A significant was observed after four weeks. The carbonation thickness grows with increasing carbonation age and replacement level that showed a high apparent porosity. Based on these better transport properties, dredged sediment and shell powders can be used as a resource of materials for the blended cement production.

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Supplementary information

Table 4. A tabulated comparison of the reported work with the reported literature.

Apparent porosity (A.P)		
Sand substituted with treated sediment aggregates [15]	Current results	
0%: 20%	0%: 17.4%	
33%: 29%	8%SS6 - 8%SS8: 18.1% - 17.8%	
66%: 40%	16%SS6 - 16%SS8: 18.3% - 18.4%	
100%: 51%	33%SS6 - 33%SS8: 18.9% - 19.4%	
Gas permeability (G.P)		
Cement substituted with metakaolin in concrete [3]	Cement substituted with treated sediment in mortar [16]	Current results
0%: $1.2 \cdot 10^{-16} \text{ m}^2$	0%: $0.82 \cdot 10^{-17} \text{ m}^2$	0%: $1.6 \cdot 10^{-15} \text{ m}^2$
5%: $1.15 \cdot 10^{-16} \text{ m}^2$	8%: $1.27 - 1.34 \cdot 10^{-17} \text{ m}^2$	8%SS6 - 8%SS8: $1 - 0.85 (10^{-15} \text{ m}^2)$
10%: $0.9 \cdot 10^{-16} \text{ m}^2$	16%: $0.92 - 1.53 \cdot 10^{-17} \text{ m}^2$	16%SS6 - 16%SS8: $1.05 - 0.89 (10^{-15} \text{ m}^2)$
15%: $0.75 \cdot 10^{-16} \text{ m}^2$	33%: $0.67-1.16 \cdot 10^{-17} \text{ m}^2$	33%SS6 - 33%SS8: $1.25 - 0.95 (10^{-15} \text{ m}^2)$
Accelerated carbonation		
Sand substituted with crushed OS [19]	Current results	
<i>One week:</i>	<i>One week:</i>	
0%: 45 mm	0%: 0.5mm	
10%: 45 mm	8%SS6 - 8%SS8: 0.5 mm	
20%: 25 mm	16%SS6 - 16%SS8: 1 - 0.5 (mm)	
	33%SS6 - 33%SS8: 2 - 1 (mm)	
<i>Three weeks:</i>	<i>Three weeks:</i>	
0%: 70 mm	0%: 6 mm	
10%: 68 mm	8%SS6 - 8%SS8: 1 mm	
20%: 50 mm	16%SS6 - 16%SS8: 6 - 1 (mm)	
	33%SS6 - 33%SS8: 8 - 11 (mm)	