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Effect of Retarders and Dispersing Agents on the Performance of Cement-Bentonite Cut off Wall

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Abstract **-** Singapore is a densely populated country and land reclamation has played an important part in relieving the continuous demand of land space. The empoldering method is considered an attractive alternate over traditional land reclamation method due to the reduced dependency on sand (which is a scarce material) and hence, a more sustainable method to increase land area. One of the key features in a polder is the seepage cut-off wall. The seepage cut-off wall consists of Cement-Bentonite (CB) mix which has sufficiently low permeability and enough strength but not be too brittle such that cracks appear. Typically, the construction of a panel of the seepage cut-off wall takes around 12-18 hours depending on the depth of the wall. Therefore, it is critical to delay the hydration reaction long enough, so that the CB mix remains workable/flowable during the construction of the seepage cut-off wall. Hence retarders or dispersing agents are used to delay the chemical reaction, thereby maintaining the workability of the mix. The retarders or dispersing agent should not alter the hydration and cementitious properties of cement. The main objective of the paper is to evaluate the effect of different retarders on two important parameters of the CB mix: unconfined compressive strength and permeability. Four chemicals are considered for the current study, wherein two chemicals are retarders, and two are retarders but with dispersing properties as well. The results showed that the CB mixes with dispersing agents have higher strength and lower permeability than CB sample with retarders.

Keywords**:** cement-bentonite, dispersing agent, permeability, retarder, and unconfined compressive strength

1. Introduction

Singapore is one of the most densely populated countries in the world. Land reclamation has been carried out since the 1960s to relieve the demand on land for housing, commercial and industry needs. Traditional method of land reclamation, which involves filling the surrounding water with sand till the land level is above the sea water level has been practised for decades. As sand is a scarce resource, its availability is becoming increasingly limited. Hence, empoldering is considered as an alternate for traditional land reclamation. Empoldering method involves constructing a dike wall and infill soil behind the dike wall to create a reclaimed land at an elevation lower than sea level. This will substantially reduce the amount of sand required as compared to traditional land reclamation. When the dike is constructed using sand, which is permeable, a seepage cut-off wall made of cement-bentonite is needed to be constructed in the dike to minimise the seepage of sea water into the polder land. The CB cut off wall should have sufficiently low permeability and adequate strength to withstand the forces and yet not be too brittle such that it will develop cracks during its service life. To achieve these criteria, a good understanding of the cement-bentonite reaction is needed. Typically, the construction of the seepage cut-off wall takes around 12-18 hours depending on the depth of the wall. Therefore, it is critical to delay the hydration reaction of cement long enough, so that the CB mix remains workable/flowable during the construction of the seepage cut-off wall. Hence, retarders or dispersing agents are used to delay the chemical reaction, thereby maintaining the workability of the mix. Apart from delaying the chemical reaction, the retarders or dispersing agent should not influence the cementation reaction of cement. Literature review suggests that the dispersing agents/retarders have been extensively studied for cement or bentonite alone or soil-cement mixes, but not for cement-bentonite mixes [1]–[4]. A review of past literature also indicates that properties of cement-bentonite slurry is dependent on the type and proportions of bentonite and cement used, and specifications should be based on performance rather than defining material quantities [5]–[8]. The main objective of the paper is to evaluate the effect of different type of retarder and dispersing agent on two important performance parameters of the CB mix: unconfined compressive strength and permeability.

2. Material and Sample Preparation

A sodium activated bentonite with 90 bbl yield grade is used in this study. The cement used in this study is a blast furnace cement (CEM III/B 42.5N). There are four types of chemical admixtures used in this study, namely B1, B2, B3 and B4 (name of the chemicals not mentioned due to confidentiality). Chemicals B1 and B2 are solely retarders, while chemicals B3 and B4 have both retarding and dispersing properties. Further chemical analysis is beyond the scope of this study.

The bentonite content (kg/m^3) in this study is defined as the mass of bentonite in 1m^3 of CB mix. Cement content (kg/m^3) is defined as the mass of cement present in 1m^3 of CB mix. Retarder content is defined as the amount of retarder present in 1m^3 of CB mix.

Firstly, the bentonite is soaked in water for two days, after which the water-soaked bentonite is mixed in Hobart mixer for 10 minutes to maintain homogeneity. Then, cement and admixture are added and mixed in Hobart mixer for 10 minutes. Finally, the sample is transferred to PVC moulds of 50 mm diameter and 100 mm in height in 3 layers. Each layer is tamped until all air voids escape the sample. The top and bottom of the samples are wrapped with one layer of filter paper followed by layer of plastic sheet. Two curing conditions are studied, namely, wet and moist curing. The samples were kept in a water bath at room temperature for wet curing and kept in a zip-lock bag with moisture inside for moist curing.

3. Experimental Program

After the desired curing duration, the samples were extracted from the PVC moulds and the bulk density of the cement-bentonite samples was noted with variations in bulk density maintained within $\pm$0.01 g/cc. After recording the bulk density, unconfined compressive strength testing and permeability testing were carried out. Figure 1 shows the pictures of the curing techniques and testing setup.

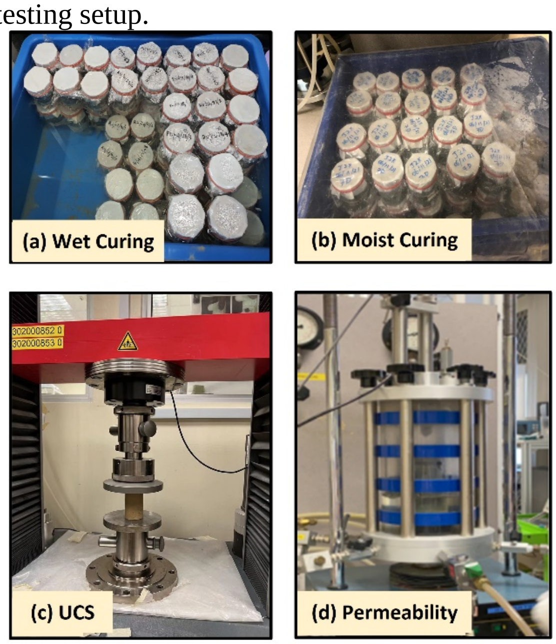

Figure 1. Pictures of (a) Wet Curing, (b) Moist Curing, (c) UCS testing setup (d) Permeability testing in triaxial setup

Unconfined compressive strength testing was carried out using Zwick universal compression testing machine. The samples were sheared at a rate of 1 mm/minute in accordance with ASTM D2166/D2166M (2013).

Permeability is measured in a triaxial setup, where the pressure gradient between the top and bottom of the sample causes the water to flow through the sample. The flexible membrane used in triaxial setup minimises the water flow through the interface, which is a problem in case of conventional rigid permeameters. In this study an effective confining stress of 100 kPa and pressure of gradient of 20 kPa is used for the flow. The samples are saturated using 300 kPa back pressure and 'B' value of 0.95 was achieved to ensure complete saturation before permeability testing.

4. Results and Discussion

The objective of the paper is to study the effect of different types of retarders/dispersing agents on the UCS strength and permeability of cement-bentonite mix. Hence, a constant cement content = 80kg/m^3 and bentonite content = 50 kg/m^3 is used. B0 is the baseline case where no chemical is used. B1& B2 refer to the two types of retarders, while B3 & B4 refer to the two types of dispersing agents.

4.1. Effect of Retarders

4.1.1. Unconfined Compressive Strength

Figure 2(a) shows the variation of unconfined compressive strength for CB mix with various retarders under wet curing condition. The baseline (B0) CB mix has higher UCS strength than the CB mix with retarder (B1 and B2 chemical), from 14 days till 91 days. Among the two retarders considered in the study, strength gain of CB mix with B2 retarder is higher than that of B1 retarder. At 91 days of curing, the CB mix with B2 retarder achieved the same UCS strength as control CB mix (B0) without any chemical, while CB mix with B1 retarder achieved lower UCS strength than control mix (B0).

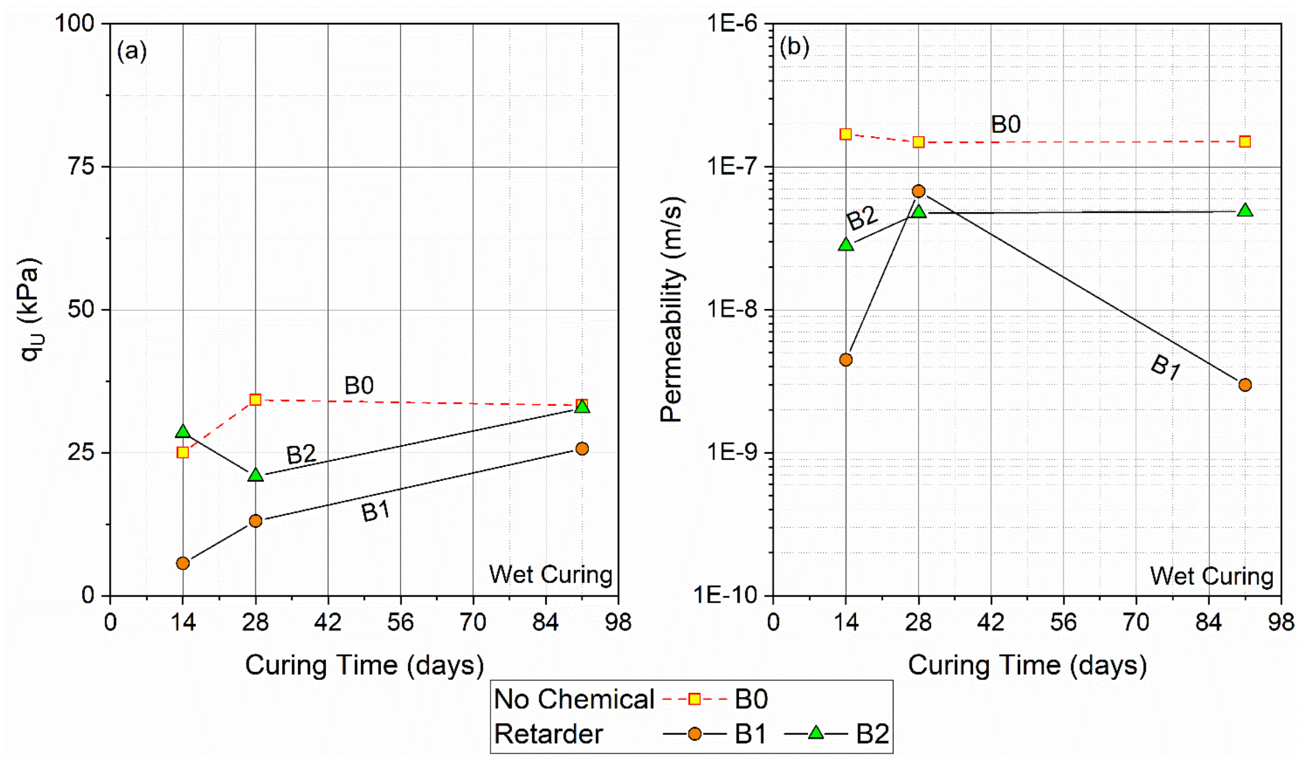

Figure 2. Effect of different retarder on (a) unconfined compressive strength and (b) permeability of wet cured CB mix.

When retarder is added to the mixture, it usually forms a diffusion barrier around the cement which increase the difficulty for water molecules to react with the unhydrated cement, thus slowing down hydration reaction and increase the dormant period of the slurry. With the delay in hydration process, there are insignificant amount of hydration products to provide the rigidity for the hardening of cement, thus allowing CB slurry to stay semi-fluid and allow sufficient time for the slurry to be casted before it finally set uniformly along the height of casting. Higher workability of CB slurry on site are favoured by contractor as they must account for some buffering time due to pumping of CB from mixing plant to the trench as well as some unforeseen delays on site. Retarders might slow down the rate of achieving the mix's strength performance but should not change the composition of hydration products [10]. Although the UCS strength of samples with B1 and B2 seem to catch up with time, retarders B1 and B2 seem to significantly inhibit the UCS strength of the CB mix till 28 days, while B2 mix allowed CB mix to gain UCS strength at least equal to control mix at 91 days.

4.1.2. Permeability

Permeability is measured in a triaxial setup, where the pressure gradient between the top and bottom of samples causes the water to flow through the sample. In this study an effective confining stress of 100 kPa and pressure gradient of 20 kPa is used. Figure 2(b) shows the variation of permeability with curing time for different retarders under wet curing condition.

The permeability of control CB mix (B0) with no chemical lies in the range of ~$2x10^{-7}$ m/s to $5x10^{-8}$ m/s. This range of permeability is not suitable for a seepage cut-off wall. The CB mix with retarders (B1 & B2) have permeability in the range of $5x10^{-8}$ m/s to $5x10^{-9}$ m/s.

In short, the control mix gives the following results at 91 days with UCS strength of 40kPa and permeability in the order of 10^{-7} m/s. Adding retarders B1 and B2 helped to reduce the permeability of CB mix compared to the CB control mix but reduced the UCS strength of CB mix compared to control mix.

4.2. Effect of Dispersing Agents

4.2.1. Unconfined Compressive Strength

Figure 3(a) shows the variation of unconfined compressive strength with curing time for CB mix with dispersing agents under wet curing conditions.

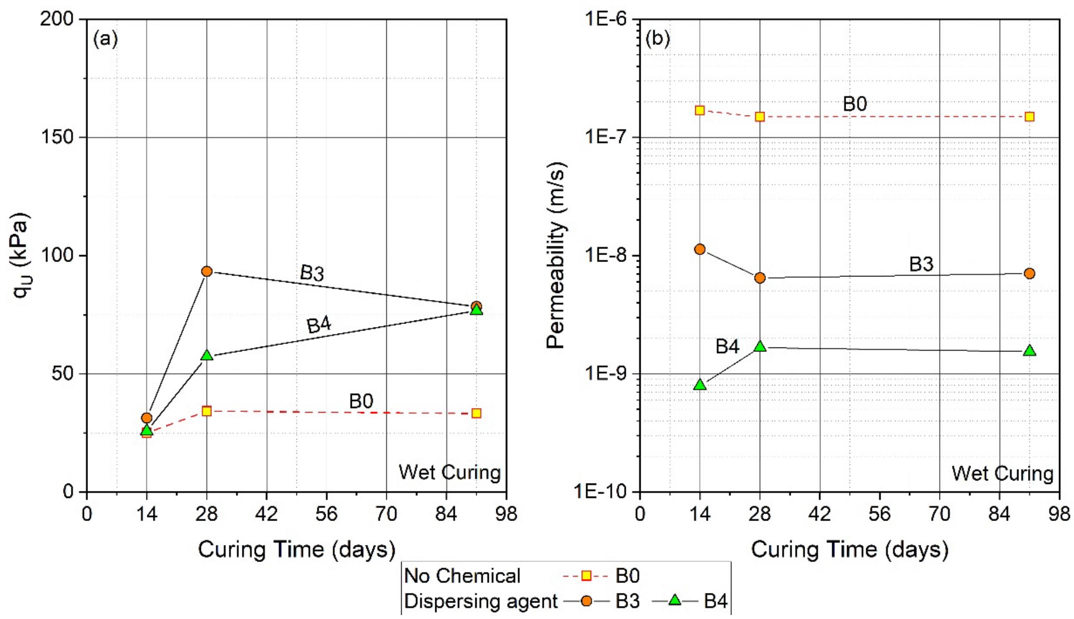

Figure 3. Effect of different dispersing agents on (a) unconfined compressive strength and (b) permeability of wet cured CB mix.

In general, CB mix with dispersing agent (B3 and B4) have higher UCS strength than control mix (B0), even as early as 14 days curing. The 14 days UCS strength of the CB mix with B0, B3 and B4 are comparable, suggesting that the retarding effect of the dispersing agent disappears after 14 days of curing unlike retarders B1 and B2.

The dispersing agent improves the flow properties of a cemented soil slurry by breaking up cement agglomerates and freeing the water. This helps in producing lower viscosity slurries [11]. There are three main mechanisms for the dispersion of particles, namely electrostatic, steric stabilization and depletion stabilization. With regards to UCS strength of the CB mix, both samples with dispersing agent (B3 and B4) achieved higher UCS strength than the CB control mix. Both CB mix with dispersing agents B3 & B4 develop similar UCS strength in short term (14 days) and in long term (91 days), but 28-day UCS strength of CB mix with B3 is higher than that of CB mix with B4.

4.2.1 Permeability

Figure 3(b) shows the variation of permeability of with curing time for CB mix with dispersing agents. The use of dispersing agent (B3 & B4) has reduced the permeability of CB mix to a permeability value of $1x10^{-9}$ m/s to $1x10^{-8}$ m/s. It is clear that the permeability of CB mix with dispersing agent is much lower when compared to the control mix.

In summary, the CB mix with dispersing agent has improved the UCS strength and reduced the permeability, exactly what is required during the construction of CB wall.

4.3. Effect of Curing Conditions

The effect of two types of curing conditions is explored in this study, namely moist curing, and wet curing. Under moist curing conditions the CB samples prepared in the PVC moulds are kept inside a zip lock with some moisture and allowed to cure under these moist conditions. This curing condition simulates the behaviour of CB wall above the water table in Singapore conditions where the ambient humidity is high. The wet curing condition, on the other hand, simulates the behaviour of CB wall below the water table.

4.3.1. Unconfined Compressive Strength

Figure 4 compares the UCS strength of CB mix under wet and moist curing condition with different retarders/dispersing agents used. Figure 4(a) compares the UCS strength between the two curing conditions when no chemical are used. Figure 4(b) and Figure 4(c) compares the UCS strength of between two curing conditions when retarder and dispersing agent are used, respectively.

Regardless of the chemicals used, the UCS strength of the CB mix under moist curing condition is always higher than that of wet curing conditions. Under wet curing conditions, the sample is in contact with the water in the curing bath, as the ends of the sample are covered with filter paper. The CB mix in the curing bath has moisture which is much lower than the surrounding water in the curing bath. This differential moisture between the sample and the surrounding curing bath causes water to flow inside the sample. So, this process could increase the post-curing moisture content of the sample and the presence of excess water could weaken the bonds in the cementitious compounds [12], causing a reduction in strength.

Under moist curing conditions, the CB samples cure in presence of the water content available within the sample and the sample have very limited moisture from surrounding. The hydration process of cement utilizes the initial moisture content present in the sample itself, so, the post-cured moisture content is lower than the initial moisture content of the sample, hence resulted in higher strength. It is assumed that the initial water content in the sample is sufficient for hydration & cementation reaction. Hence, with respect to strength consideration, CB wall below the water table, which is similar to wet curing, would have lower UCS strength and thus will be critical.

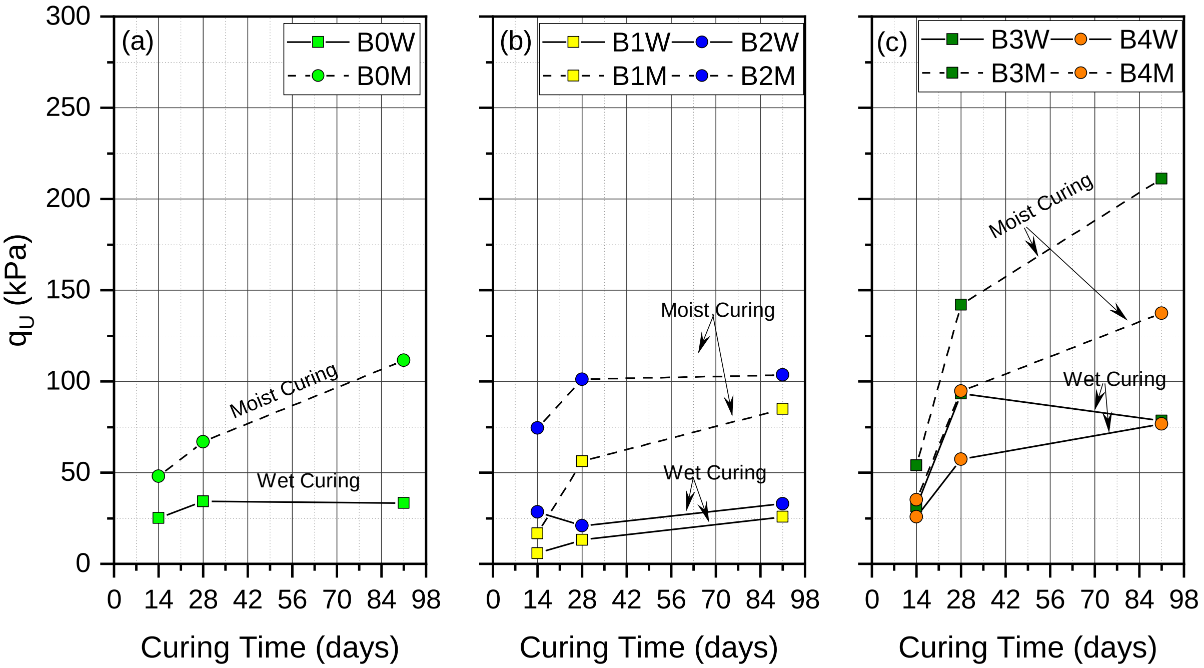

Figure 4. Comparison of UCS strength of CB mix under wet and moist curing conditions when (a) no chemical, (b) retarders and (c) dispersing agents are used.

4.3.2. Permeability

Figure 5 compares the permeability of CB mix under wet and moist curing condition when different retarders/dispersing agents are used. When no chemical is used, the moist cured samples have lower permeability then the wet cured samples (Figure 5a). When retarders B1& B2 were used, the permeability at moist curing is rather constant, while for wet curing permeability varied a lot with respect to curing time (Figure 5b). Figure 5c shows that the permeability of wet cured samples are higher than that of moist cured samples when dispersing agents are used. Overall, apart from the erratic data of wet cured samples with B1 retarders, it seems that there are no significant difference in permeability between wet cured and moist cured samples.

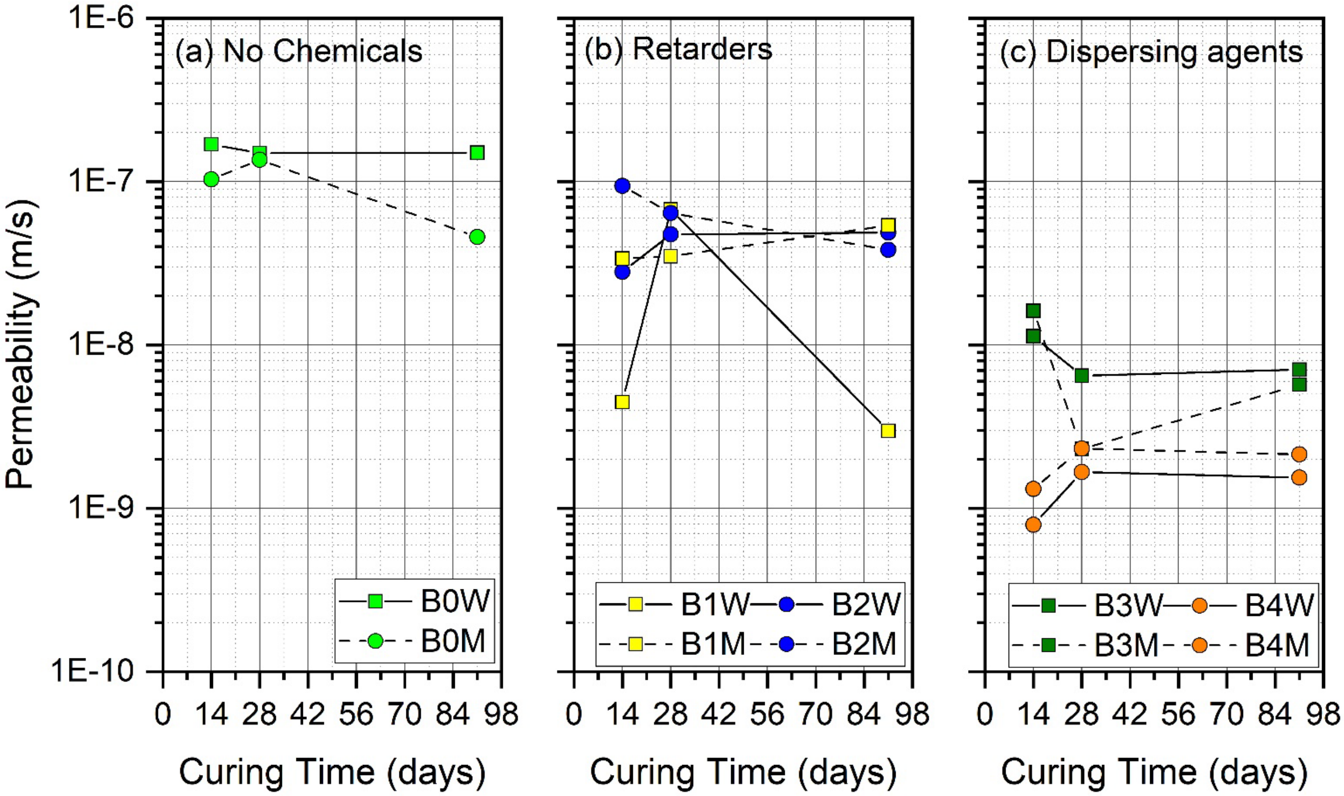

Figure 5. Variation of permeability with (a) no retarder, (b) B1 & B2 retarder and (c) B3 and B4 dispersing agent.

4.3. Comparison between effect of retarder and dispersing agent

Figure 4(b) and Figure 4(c) compare the UCS strength of CB mix with retarders and dispersing agent. Under both wet and moist curing conditions, the CB mix with dispersing agent has higher UCS strength than CB mix with retarders. Under moist curing conditions, CB samples with both types of dispersing agent achieve 100 kPa UCS strength at 28 days and most importantly have a 91-day UCS strength of below 300 kPa, which is typical range of UCS strength expected for CB wall. In case of retarders, only CB sample with B2 retarder was marginally able to achieve a UCS strength of 100 kPa at the end of 91 days. Hence, with regards to performance of the CB mix in terms of UCS strength, dispersing agent perform better than retarders.

Figure 5(a) and Figure 5(b) compare the permeability of CB mix with retarders and dispersing agent. The permeability of CB samples with retarders range between $1x10^{-7}$ to $1x10^{-8}$ m/s (except B1 wet curing), while permeability of CB samples with dispersing agent range between $1x10^{-8}$ to $1x10^{-9}$ m/s. The permeability of CB samples with dispersing agents are one order magnitude lower than CB samples with retarders, suggesting that dispersing agent are more suitable for cut-off wall construction using cement-bentonite.

Dispersing agents are usually added to colloidal mixes to help lessen the amount of clumping to obtain a more homogenous mixture. Their main function is to reduce the adhesion between particles and prevent flocculation or agglomeration. Dispersants are generally divided into two categories: inorganic dispersants and organic dispersants. Commonly used inorganic dispersants include silicates and alkali metal phosphates (e.g., sodium tripolyphosphate, sodium hexametaphosphate, and sodium pyrophosphate). Organic dispersants include cellulose derivatives, polycarboxylates, and guar gum [13].

On the other hand, retarders are chemical additives that are commonly used to reduce the speed of cement hydration and delay setting as a result. Retarders act by binding to the calcium ions in cement and inhibit the growth of ettringite crystals

[14]. Retarders often contains lignosulfonate, hydroxycarboxylic acids, carbohydrate, inorganic salts and organic acids. The most common ones are calcium lignosulfonate and molasses [15].

For the current dosage of cement and bentonite content used in this study, B3 dispersing agent has slightly higher UCS strength than B4, but with regard to permeability, B4 dispersing agent outperforms B3 by a large margin. Hence, B4 dispersing agent would be more suitable for CB wall construction.

5. Conclusion

The use of retarders and dispersing agents are crucial in the construction of cement-bentonite cut-off wall, as they ensure the adequate flowability of the cement-bentonite mix for pumping CB from mixing plant to the actual CB trench. This paper summarizes the effect of using different types of retarders and dispersing agent on the UCS strength and permeability of cement-bentonite cut-off wall. A series of tests with two types of common retarders and two types of dispersing agent were used with CB mix. UCS strength and permeability of CB mix were determined at 14-, 28- and 91-days curing time under two different curing conditions (wet & moist curing conditions). The results show that

a) The UCS strength of CB mix with retarders is generally lower than that of CB mix without any chemicals, up to a curing period of 28 days. At 91 days curing, the UCS strength of CB mix with retarders is comparable to the control mix (without chemical).
b) CB mix with dispersing agents achieved higher UCS strength than CB mix without any chemicals at curing period of 28-91 days. Among the two dispersing agents considered in this study, B3 dispersing agent achieved higher UCS strength in the long term (91 days).
c) Regardless of the chemicals used, UCS strength performance of moist cured CB samples is higher than the UCS strength performance of wet cured CB samples.
d) Permeability of CB mix with dispersing agent is lower than CB mix with retarders which in turn is lower than CB mix with no chemicals. Among the dispersing agents considered in this study, CB mix with B4 achieved the lowest permeability.
e) There is no significant difference in permeability value of CB mix cured under wet or moist conditions.

6. Acknowledgement

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