Characterisation of the performance of sustainable grout containing bentonite for geotechnical applications

CHARACTERISATION OF THE PERFORMANCE OF SUSTAINABLE GROUT CONTAINING BENTONITE FOR GEOTECHNICAL APPLICATIONS

Mohammed Sonebi[1], David Hughes[1], Ruth Harley[1], Kaine Lynch[1]

[1] *School of Planning, Architecture and Civil Engineering, Queen's University Belfast, UK*

The grouts used in sealing or backfilling boreholes should ideally be selected to be compatible with the insitu field instruments installed in the borehole and also be engineered to match closely the geotechnical properties of the parent soils. A stable grout can be made using cement with various proportions of bentonite. The grout stability is very important during both the liquid and set conditions. The liquid grout fluidity should be as viscous as possible to avoid segregation, yet fluid enough to be easily pumpable and fill voids and over-break in the borehole. This paper investigates the effect of bentonite on the fresh and rheological properties of cement-based grouts in order to develop a stable grout to be used in these geotechnical situations. These properties were evaluated by the mini-slump flow, marsh cone flow time, Lombardi plate cohesion meter, static bleeding, yield stress and plastic viscosity values. Additionally, the compressive strength at 3 days, 7 days and 28 days were also investigated. The key parameters investigated were the dosages of bentonite and water-to-binder ratio (W/B). Test results showed that the dosage of bentonite had a significant effect on the fluidity, rheological properties and compressive strength of grout. The increase in the dosage of bentonite led to increasing the values of flow time, plate cohesion meter, yield stress and plastic viscosity, and reducing the mini-slump results, the static bleeding and the compressive strength at 3 days, 7 days and 28 days. Conversely, the increase in W/B led to decreasing the values of flow time, plate cohesion meter, yield stress, and plastic viscosity and the compressive strength, while increasing the mini-slump results and bleeding. Some recommendations for suitable mix proportions for use in soil boreholes are made.

Corresponding author's email: m.sonebi@qub.ac.uk, 44 2890 974013

Introduction

Bentonite powders are widely used in many industrial applications and come in numerous forms. Bentonite is a natural clay material, which contains mainly smectites (montmorillonite), and secondary minerals such as quartz, calcite and micas [Besqa et al. 2003]. Bentonite cement and clay cement are still the most commonly used grouts because they are easy and cheap to prepare (Luckham et al. 1999). There have been many proposals for improving the penetration of conventional grouts (Luckham et al. 1999). Clay and cement deflocculants (Gandais and Delmas, 1987) disperse the grains of the basic constituents and so improve stability and reduce viscosity to below 5 centipoise. This improves penetration because, in addition to low viscosity, these grouts retain water much more strongly. Therefore, unlike standard grouts, they do not lose their mix water in the ground and retain their low viscosity for longer. Bleeding of cement-based grouts reduces the effectiveness of compensation grouting operations. Compensation grouting involves the injection of a grout to heave the soil and compensate for settlements resulting from ground loss during tunnelling. A grout bleeds at the incipience of the injection pressure. Water is squeezed out from pores between cement particles, into the ground, in a similar process to water drainage in soil consolidation. Research has been reported on the rheology and viscosity of some grouts (Nehdi et al., 2002, Sonebi, 2006, 2007, 2010), and on the consolidation characteristics of cement based grouts, but less is understood on the correlation with bleeding.

One of the important attributes of a bentonite suspension is its ability to stabilize the sides of a borehole or trench panel in otherwise unstable ground without recourse to casing or some form of shuttering. The theory of support is still under investigation but depends, at least in part, upon a thin, tough film of high solids content bentonite suspension providing a ‘filter cake’ of low permeability at the wall, with outward support from intermixed soil-bentonite slurry within. Trenches and boreholes may be constructed to any depth within the limits of the excavation and concreting methods employed, the bentonite slurry filling the void and maintaining it against collapse. Structural reinforced diaphragm walls, water cut-off walls, pile elements or piles may be made in this manner.

In this paper an experimental study is conducted on the influence of the percentage of bentonite, water/binder ratio, and the dosage of superplasticiser of the fresh properties, rheological parameters, bleeding and compressive strength at 3d, 7 d and 28 d of sustainable grouts for geotechnical applications.

Materials and Test Procedures

The grout mixtures were prepared with a water-to-binder ratio (w/b) varied from 0.55 to 0.80. Ordinary Portland cement CEM II 42.5N, specified by BS EN 197-1 standards: 2000 and the sodium activated bentonite was used at 5% and 7%, replacement of cement by mass. It consists of about 80% of hydrous silicate of alumina comprised essentially of the clay mineral montmorillonite. The chemical and physical composition of CEM II and bentonite are given in Table 1.

The mixes were prepared in 2-L batches using a 5-L planar-action high-shear mixer. Cement and bentonite were added together to the mixer and mixed for one minute at low speed (140 rpm). Tap water (16 ± 0.5 °C) was introduced within 2 min, at the end of which the mixer was stopped and any lumps of solids formed were crushed (1 min). Subsequently, the grout was mixed again for 2 min at a higher speed of 285 rpm and for 1 min at the lower speed of 140 rpm.

The saturation dosage of SP was measured with a Marsh cone with an opening orifice of 10 mm (BS EN 445:2007). The mixing procedure was as above, however, tap water at 16 ± 0.5°C was used, and the last sequence of mixing (1 min at low speed) was omitted.

For all tests, the timing is given from the first contact between cement and water (zero time). The mini-slump spread test was carried out immediately after the end of mixing (i.e at 7 min). The transparent cone-shaped mould described elsewhere [Sonebi, 2006a] was used in this study in combination with a smooth Plexiglas plate. The test consists in filling the cone with grout, and gently lifting it over approximately 30 s after placement of the grout. When the flow stopped, the spread of the grout was measured in two perpendicular directions. The reported mini-slump values correspond to the mean values determined on the two-perpendicular directions. Marsh cone test was carried out using a metal cone with an orifice diameter of 10 mm. The test consisted in pouring 1 litre of grout into the cone. After a waiting time of 15 s, the orifice was opened and the time taken for each 100 ml of grout to flow through the orifice was recorded, and the measurements were completed upon collecting 700 ml of grout.

The rheological measurements were carried out with a computer-controlled vane rheometer (Haake VT550). At 15 ± 1 min, approximately 800 ml of the sample was put into a plastic container into which the vane was plunged. After 30 s rest, the test was started, and the data automatically collected. After 30 s rest, the test was started, and the same testing parameters as above (velocities and their durations) were followed. The shear rate steps used in this investigation are presented in Fig. 1. For each step, when the equilibrium was reached, the strain rate was increased from an initial value of 0.188 s^{-1} to a top value of 41.6s^{-1} (ascending curve), and afterward, it is decreased to ending the descending curve. The rheological parameters, yield stress (τ_0) and plastic viscosity (μp), were obtained from the descending curve using Herschel-Bulkely model to fit to the experimental data.

The cohesion of grout was determined at 30 ± 1 min with a Lombardi plate cohesion meter. A thin galvanized steel plate (100×100×1 mm) with known weight was immersed in the grout and hung on a stand placed on an electronic balance. The difference in weight values before and after immersion into the grout (dW) is determined. This test was followed by the fresh density measurement of the grout with a mud balancer and the thickness of the grout on the plate is then calculated as the ratio between dW and density of the grout with 2 sides of plate.

Static bleeding was measured according ASTM C-940 test method which determines the amount of expansion and accumulation of bleed water at the surface of freshly mixed hydraulic-cement grout. It consists of placing the cement grout at rest in a graduated transparent cylinder (1000 mL) and measures the expansion and the amount of bleed water at various time intervals.

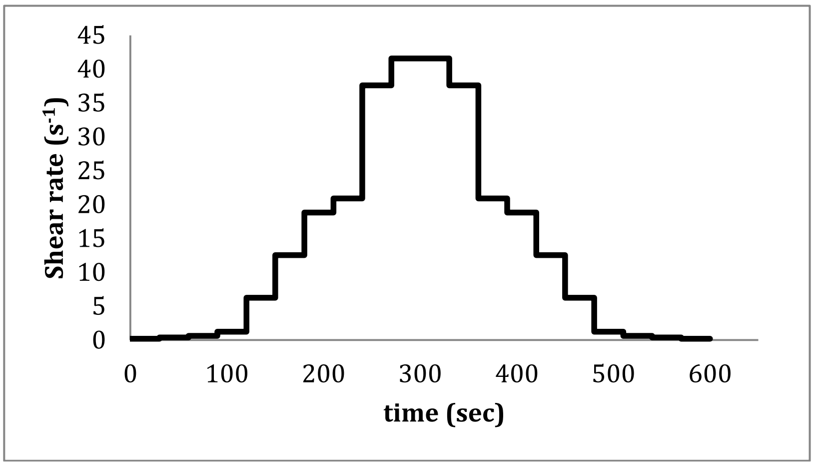

Fig. 1 – Shear rate steps applied to paste using step-by-step procedure

Table 1 - Chemical and physical properties of cement and bentonite

	Material	
	CEM II	Bentonite
SiO_2	18.03	53.3
Al_2O_3	5.32	17.0
Fe_2O_3	2.87	5.55
MgO	1.67	3.8
CaO	62.83	5.13
Na_2O	0.07	2.80
K_2O	0.70	0.90
SO_3	2.83	--
P_2O_5	0.09	--
LOI	6.02	10.77
% passing 45 µm sieve	85	--
% passing 150 µm sieve	--	95
Specific gravity	3.08	2.55
Specific surface area [m^2/kg]	360	650
Traces	--	0.72

RESULTS AND DISCUSSION

Fluidity

The variations of mini-slump values for mixes prepared with different percentages of BT (5%, and 7%) and W/B are summarized in Figure 3. As expected, for the mix without BT (only OPC) and made with W/B = 0.60, the addition of BT at 5% and 7% resulted in a reduction of fluidity, which is due to a high surface area of bentonite. For any given percentage of BT, the increase of W/B is shown to exhibit a significant effect on mini-slump due to the availability of more free water to lubricate the particles. This results in greater fluidity. For lower W/B (0.60), the increase of BT from 5% to 7% led to a greater reduction of the fluidity (34%) and in the case of W/B=0.70, the reduction was only 4% when BT increased from 5% to 7%. This may be due to the ultra fine nature of BT, which is likely to reduce the amount of water per unit surface area. For example, in the grout with 5% BT, the increase of W/B from 0.55 to 0.60 led to an increase of mini-slump by 38%.

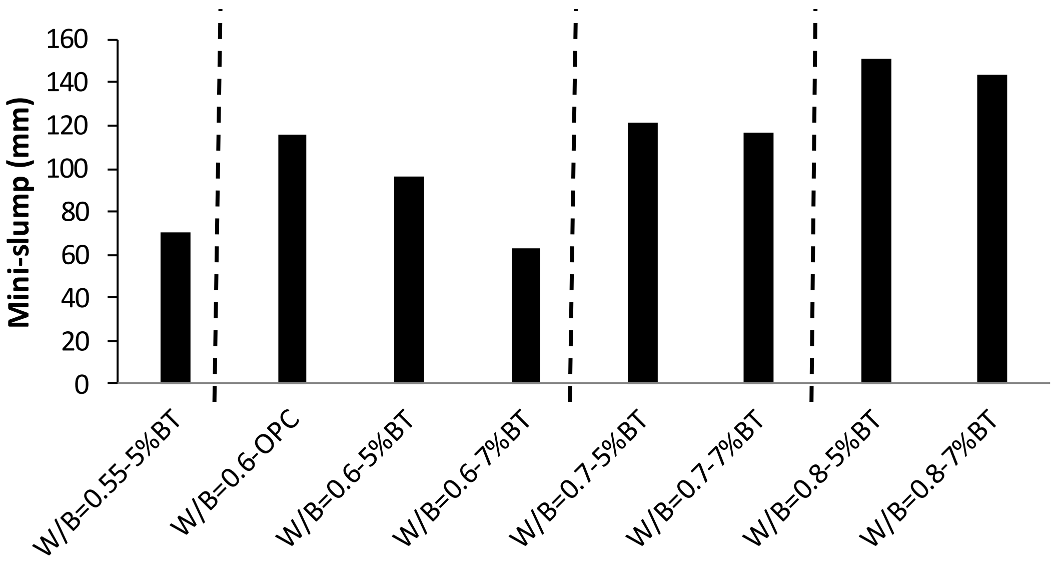

Fig. 2 – Effect of % of bentonite and W/B on mini-slump

Flowability

Figure 3 presents the Marsh flow time results of grouts made with 5% and 7% BT with variation in W/B. For any given W/B, an increase in percentage of BT led to a reduction in the flow time compared to the control mix (none BT). On the other hand, for a fixed percentage of BT, the increase of W/B exhibited a better flowability. This increase in free water can contribute in reducing the friction between particles, hence improveing the flowability and deformability of the grout. However, the increase of BT led to an increase of flow time, especially in the case of the mix made with a lower W/B of 0.60. The increase in BT from 5% to 7% resulted in an increase in flow time. For example, the use of 5% BT resulted in increasing the flow time from 3.7 s to 5.8 s (57% increase) in the case of the mix made with W/B = 0.60. In the case of the mix made with 7% BT, this increase was higher to 332% (from 5.8 s to 25 s). This is may be attributed to the high surface area of BT, thus absorbing some of the free water. However, for mixes with 0.70 and 0.80 W/B, the increase of BT from 5% to 7% led to a slight increase in flow time.

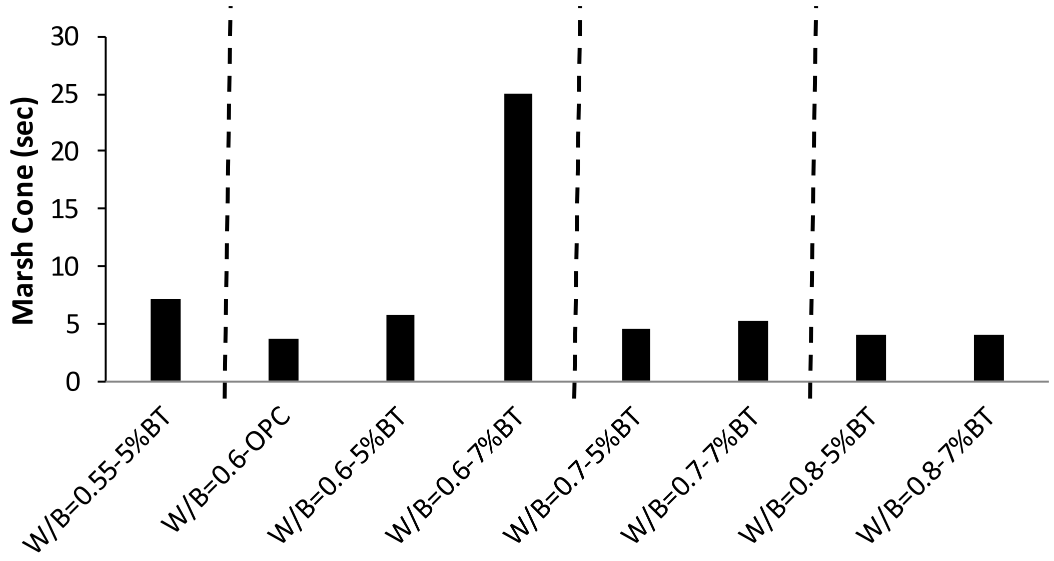

Fig. 3 - Variations of Marsh time with percentages of BT and W/B

Plate cohesion

The effect of increasing BT content and W/B on cohesion is shown in Figure 4. As expected, adding BT in grouts (OPC mix) resulted in an increase in the cohesion. This may be due to the fine nature of BT, which is likely to reduce the amount of free water per unit surface area, and therefore increased the cohesiveness of grout. For example, for the mix with W/b = 0.60, the addition of 5% BT led to an increase in cohesion plate by 244%. However, for any given percentage of BT, the increase in W/B reduced the cohesion of gout.

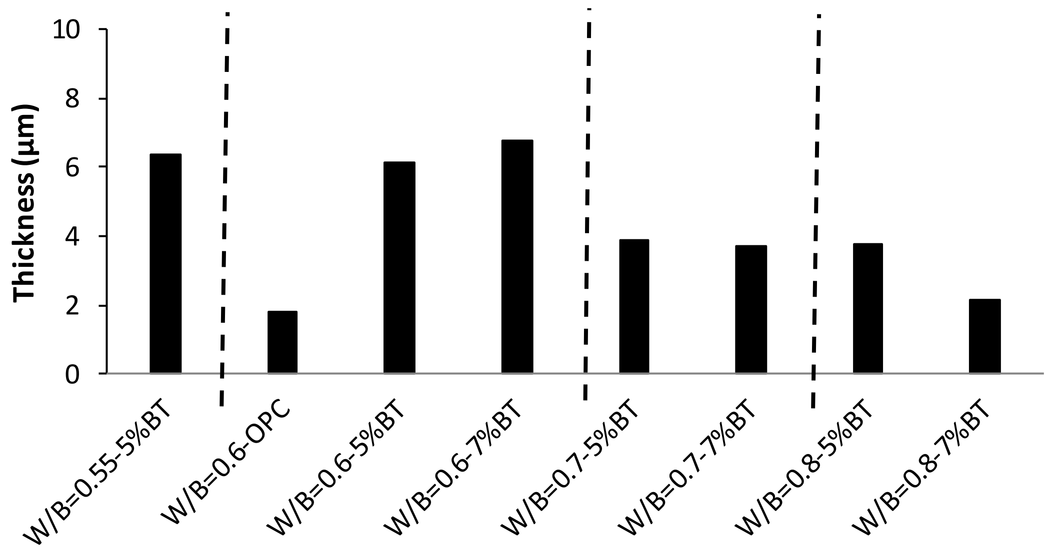

Fig. 4 - Variations of plate cohesion with percentages of BT and W/B

Static bleeding

Figure 5 presents the static bleeding results of grouts made with 5% and 7% BT with variation of W/B. It can be noticed that the addition of BT led to a significant reduction in bleeding. With the addition of bentonite, a homogenous colloidal mix was obtained by improving the viscosity which led to a reduction of bleeding and sedimentation. However, as expected the increase in W/B resulted in higher bleeding. The highest bleeding was obtained with higher W/B = 0.80. For mix with a W/B of 0.60, adding 7% of BT kept the bleeding rate lower than 2%.

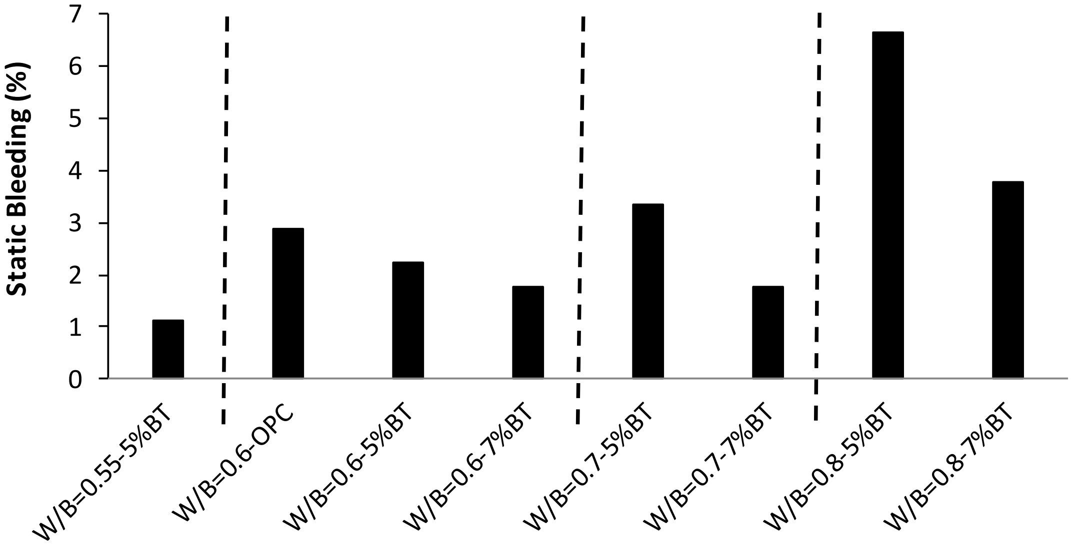

Fig. 5 - Variations of static bleeding with percentages of BT and W/B

Rheological parameters

Yield stress

Figure 6 presents the yield values of grout mixes made with various percentages of BT and W/B. For the mix made without BT, the increase in the percentage of BT resulted in an increase of yield stress value, particularly from 5% to 7% with W/B of 0.60. In this case, the increase of yield stress was nearly seven times. Conversely, for mix made fixed percentage of BT, the increase in W/B led to a reduction in yield stress and improvement of fluidity. This can be attributed to the existence of face-face (FF) and edge-edge (EE) flocculated structures [Luckham el al. 1999].

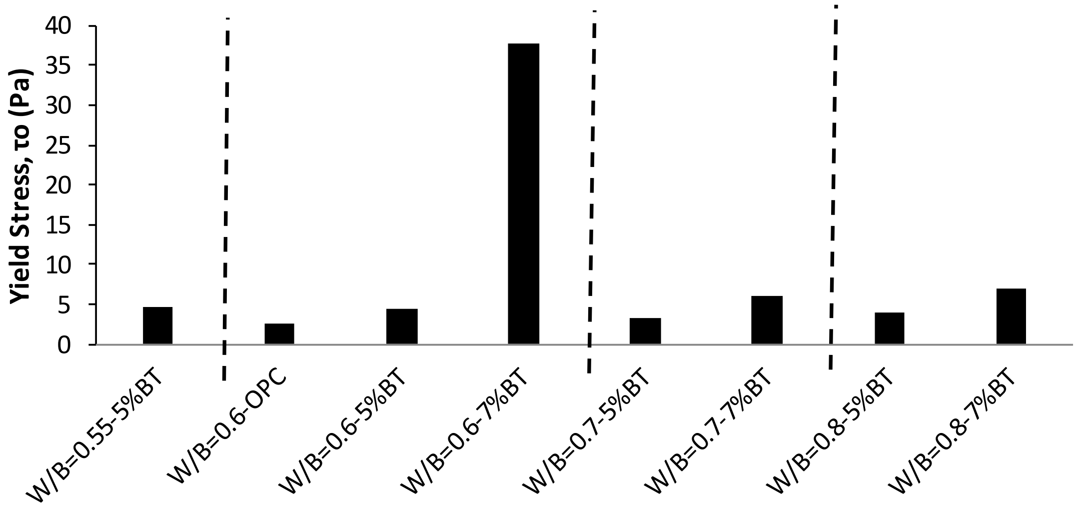

Fig. 6 - Variations of yield stress with % BT, and W/B

Plastic viscosity

The variations of the plastic viscosity with the percentage of BT and W/B of all the investigated grout mixes are presented in Figure 7. For mixes with BT, the plastic viscosity is affected by W/B. Similarly for the yield stress, for any given W/B, the increase in the percentage of BT resulted in an increase of plastic viscosity. For example, for mix made with W/B of 0.60, the addition of 7% BT resulted in an increase in plastic viscosity of 126% compared to the mix without BT. Comparatively, increasing the percentage of BT led to higher plastic viscosity, resulting in higher Marsh cone flow time values. As indicated earlier, this behaviour is attributed to the high surface area of bentonite.

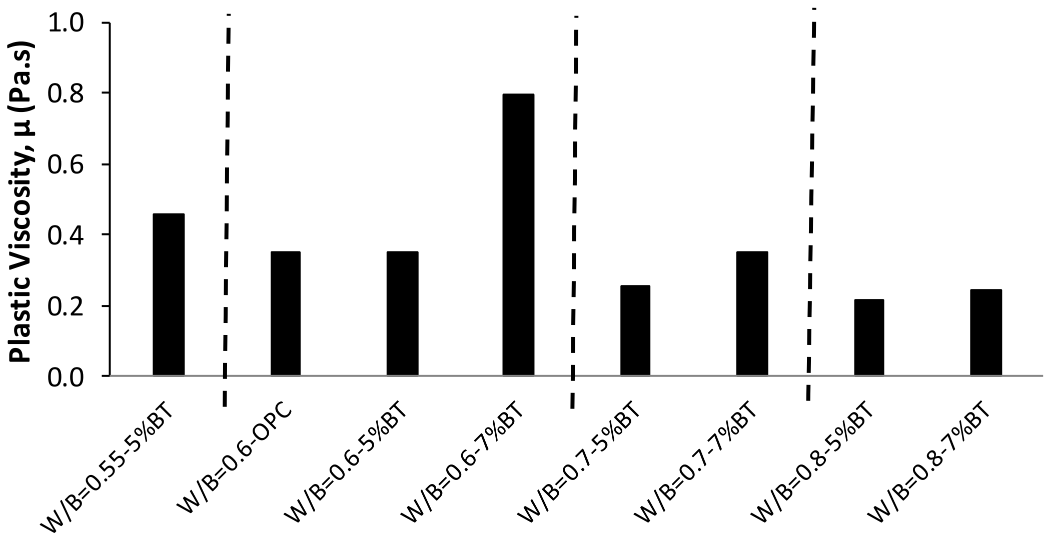

Fig. 7 - Variations of plastic viscosity with % BT, and W/B

The replacement of cement by bentonite led to an increase of the yield value and plastic viscosity for any given W/B. When the bentonite is incorporated into the grout in the fresh state it has a direct influence on the water demand required in the mix to ensure a given fluidity level. This behaviour confirms the fact that additions of high surface area mineral particles to cement grout causes the need of higher proportions of water in order to keep the workability of the mix. If the water content is kept constant, an increase of BT content will promote the packing of particles, decreasing the volume between them and decreased the free water in the system. Thus, there is a higher internal friction between solid particles, which contributes to increasing the rheological parameters of the mixes. Therefore, the replacement of cement by BT at levels 5% and 7% significantly affects the flowability of the mixes (higher plastic viscosity and yield stress values). In the case of increasing W/B, the rheological parameters were reduced and the bleeding is increased which is less suitable for grout injection.

Compressive strength

Fig. 8 presents the variation of compressive strength at 3 d, 7 d and 28 d with the percentage of BT and W/B. As expected, the increase of W/B led to a reduction in compressive strengths. The addition of BT indicated that the compressive strengths at 3d were improved, however, the incorporation of 5% of BT shown a reduction in compressive strength at 7 d and 28 d compared to the mix without BT (mix made with W/B = 0.60). With 7% BT, all compressive strength at 3d, 7d and 28 d were increased compared to the reference mix with W/B = 0.60. This can be attributed to the large pozzolanic contribution of bentonite [Targan et al. 2002].

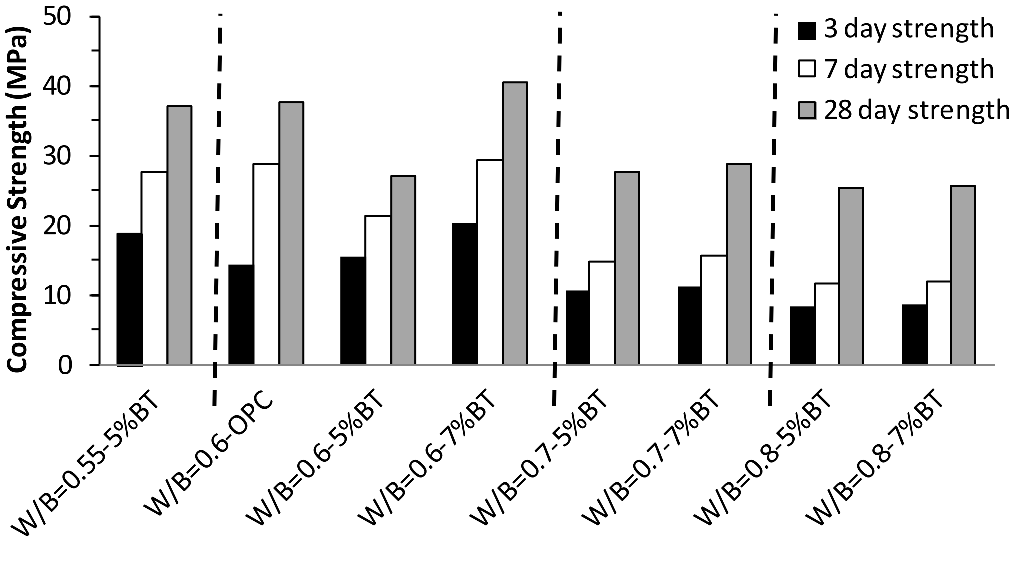

Fig. 8 - Variations of compressive strength at 3d, 7d and 28 d with % BT, and W/B

Conclusions

Based on the results presented in this paper to produce sustainable grouts, the following conclusions can be made:

- The percentage of bentonite (BT) had a significant effect on mini-slump, flow time, plate cohesion meter, bleeding, yield stress, plastic viscosity, the the compressive strength.

- The increase in the dosage of BT led to increasing the values of flow time, plate cohesion meter, yield stress and plastic viscosity, while reducing the mini-slump values and bleeding. This is ascribed to the fine nature of BT particles and BT made mix more homogenous colloidal system.
- The increase in W/B led to increasing the mini-slump values (fluidity), while reducing the values of yield stress, plastic viscosity, plate cohesion, and Marsh cone flow time of grout containing fine particles of bentonite.
- The use of BT resulted in higher yield stresses and plastic viscosity values of grout, which may require higher water contents to ensure a given deformability.
- For compressive strength at 3, 7 and 28 d, the increase in W/B led to a reduction of compressive strengths while the use of 7% BT led to an improvement of compressive strength at 3 d, 7 d and 28 d.
- For field geotechnical applications, selected mix with W/B of 0.60 and 7% BT will be tested in soil boreholes to investigate the in-situ performance in particular the response time of piezometers to changes in pore water pressure in the parent soil.

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