

Comparison of the effect of lithium bentonite and sodium bentonite on the engineering properties of bentonite-cement-sodium silicate grout

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Abstract. This paper focuses on the engineering properties of Bentonite-Cement-Sodium silicate (BCS) grout, which was prepared by partially replacing the ordinary Portland cement in Cement-Sodium silicate grout with lithium bentonite (Li-bent) and sodium bentonite (Na-bent), respectively. The effect of different Water-to-Solid ratio (W/S) and various replacement percentages of bentonite on the apparent viscosity, bleeding, setting time, and early compressive strength of BCS grout were investigated. The XRD method was used to detect its hydration products. The results showed that both bentonites played a positive role in the stability of BCS grout, increased its apparent viscosity. Na-bent prolonged the setting time of BCS, while 5% of Li-bent shortened the setting time of BCS. The XRD analysis indicated that the hydration products between the mixture containing Na-bent and Li-bent did not differ much. Using bentonite as supplementary cementitious material (SCM) to replace partial cement is a promising way to cut down on carbon dioxide emissions and to produce low-cost, eco-friendly, non-toxic, and water-resistant grout. In addition, Li-bent was superior to Na-bent in improving the strength and the thickening of BCS grouts.

Keywords: cement-sodium silicate grout; bentonite; supplementary cementitious materials; global warming; engineering behavior

1. Introduction

The Antarctic Ice Sheet is accelerating melting (Shepherd *et al.* 2018), and the latest data suggests that they may collapse if anthropogenic warming worsens (Dickens *et al.* 2019). The melting of glaciers will raise the global sea level (Shepherd *et al.* 2019), harm the balance of natural ecosystems (Bronsealer *et al.* 2018), and threaten human survival (David *et al.* 2013). Carbon dioxide plays a vital role in global warming (Khaheshi *et al.* 2019). In the past decades, carbon dioxide from power plants, refineries, cement factories, etc. has increased the amount of carbon dioxide in the atmosphere (Martin *et al.* 2012). The sources of carbon dioxide emission in the cement industry are calcareous materials and fossil fuel. They are emitted by the decomposition of calcareous materials in kilns, direct coal combustion, and indirect electricity consumption during the cement production process (Feng *et al.* 2018, WBCSD/IEA 2009, Xu *et al.* 2012). Shi *et al.* (2011) noted that the carbon dioxide produced by cement factories accounts for 6-7% of global carbon dioxide emissions. Many efforts have been made to reduce the carbon dioxide emissions associated with cement production (Benhelal *et al.* 2013, Huntzinger and Eatmon 2009, Shi *et al.* 2011, Xu *et al.* 2015). Supplementary cementitious materials (SCMs) have emerged at the right moment (Al-Amoudi *et al.* 2019, Sharma and Bansal 2019). The SCMs covers a broad range

of materials, including both pozzolanic and hydraulic materials (Thomas 2013), such as silica fume (Imam *et al.* 2018), fly ash (Paliwal and Marua 2017, Sunil *et al.* 2017), ground granulated blast-furnace slag (Petra and Mukharjee 2018), metakaolin (Nas and Kurbetci 2018), rice husk ash (Celik and Canakci 2015) and natural pozzolans (Benyahia and Ghrici 2018, Juenger and Siddique 2015, Lothenbach *et al.* 2011, Siddique and Khan 2011). The use of such materials greatly reduces carbon dioxide emissions (Yang *et al.* 2015) and utilizes industrial by-products (Lothenbach *et al.* 2011).

At present, natural clay minerals are favored by researchers around the world for their unique properties and are extensively used in cement-based materials to replace cement (Andrejkovičová *et al.* 2015, Man *et al.* 2019). Bentonite is a highly colloidal ductile clay mineral formed by alteration of volcanic ash in shallow sea and lagoons areas (Alexander *et al.* 2018, Pusch 2015). Chemically and structurally, bentonite is regarded as a hydrous aluminum silicates consisting of one alumina octahedral (O) sheet and two silica tetrahedral (T) sheets, known as a 2:1 (TOT) structure (Liu *et al.* 2018). The typical properties of bentonite are tightness, ductility, expandability, thixotropy, and cation exchange capacity (Huang *et al.* 2016). Its tightness is of great importance for sealing hazardous waste from groundwater (Pusch 2015) and makes bentonite be used as a buffer or backfill material to handle nuclear waste (Ye *et al.* 2016) or other wastes. Additionally, bentonite has tremendous water absorption ability and has been successfully applied in hydraulic engineering such as dams (Drochytka and Magdaléna 2017), cut-off walls (Ata *et al.* 2015, Koch 2002), and grouting. It is also an

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Table 1 The property of water glass

Parameters	Unit	Values
Baume degree	°Bé	50
Density modulus	g/cm ³	1.53
PH	-	2.4
	-	13

Table 2 Chemical compositions of the raw materials

Raw materials	Compositions (in mass %)										
	SiO ₂	Al ₂ O ₃	CaO	MgO	Fe ₂ O ₃	K ₂ O	Na ₂ O	TiO ₂	Li ₂ O	SO ₃	LOI*
Li-bent	65.89	13.60	1.94	3.79	1.80	0.58	0.31	0.23	0.74	-	10.79
Na-bent	63.43	17.88	2.22	3.05	2.06	0.90	0.98	0.13	-	-	8.09
Cement	24.06	6.34	59.89	0.98	3.56	-	-	-	-	2.24	2.07

*LOI: Loss on ignition.

environmentally friendly and relatively cheap material that is widely distributed worldwide. Bentonite, as an SCM, has been studied by many researchers. Wong *et al.* (2013) showed that the application of a 10% substitute of cement using bentonite in stabilizing peat improved the unconfined compressive strength and reduced permeability. Zhao *et al.* (2019) indicated that a high replacement level of bentonite could improve the flexural deflection capacity of engineered cementitious composites. Man *et al.* (2019) found that 10-15% replacement of bentonite ameliorated the microstructural integrity of bentonite-magnesium phosphate cement mortars by filling the pores. Shabab *et al.* (2015) noted that using bentonite and fly ash as SCMs in mass concrete reduced the hydration heat that caused the thermal cracking of concrete. However, there is limited data on bentonite as SCM in Cement-Sodium Silicate (CS) double grout. The CS grout is most commonly applied in sealing engineering (Li *et al.* 2019) due to its wide raw material sources, controllable setting time and low cost. But the poor water resistance and high bleeding limit its application. Studies have shown that bentonite can reduce bleeding and improve water resistance of grouts (Azadi *et al.* 2017, Sha *et al.* 2018). Thus, replacement of some cement with bentonite may both reduce carbon dioxide emissions and improve the properties of CS grout.

The purpose of this experiment is to compare the engineering properties of Bentonite-Cement-Sodium silicate (BCS) grout, which was prepared by partially replacing the ordinary Portland cement in CS grout with sodium bentonite (Na-bent) and lithium bentonite (Li-bent), respectively. The effect of different Water-to-Solid ratio (W/S) and various replacement percentages of bentonite on the apparent viscosity, bleeding, setting time, and early compressive strength of BCS grout were investigated. The hydration products of BCS grout containing Li-bent and Na-bent were separately analyzed by the XRD method. The significant outcome of this paper is to understand the effect of Na-bent and Li-bent on the engineering performance of BCS grouts, and the results could be followed in a water-rich area where temporary grouting is required.

2. Materials and method

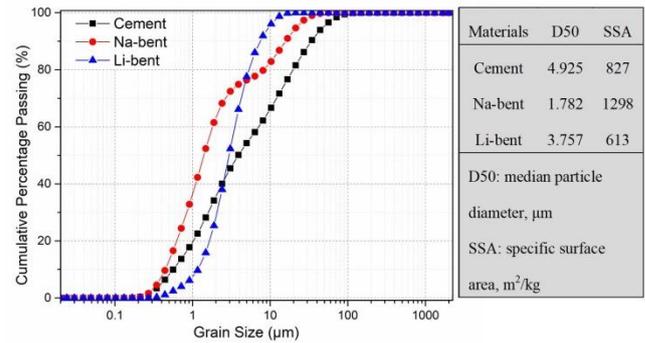


Fig. 1 The grain size distributions of raw materials

2.1 Materials and design

The BCS grouts consisted of cement, bentonite and sodium silicate solutions (also known as water glass). The cement was ordinary Portland cement P.O 42.5 provided by Tangshan Jidong Cement Co., Ltd, Tangshan, Hebei Province, China. The water glass was produced by Beijing Hongguang Science and Technology Co., Ltd, China. The property of water glass is present in Table 1. Li-bent and Na-bent were produced by Changzhou Fengshuo Chemical Co., Ltd and Shandong Weifang Hongxiang Bentonite Factory, respectively. The chemical compositions of the raw materials are present in Table 2. The particle size distribution of Li-bent, Na-bent, and cement was given in Fig. 1. It shows the median particle size (D_{50}) of cement is bigger than that of Li-bent, and Na-bent has the smallest particle size. Smaller median particle sizes generally promote cement hydration (Bentz *et al.* 1999) and are easier to be injected to achieve better grouting effect (He *et al.* 2016). The specific surface area (SSA) of raw materials was examined by a Betterisize 2000 laser particle size distributor. The SSA of Li-bent, Na-bent, and cement was 613 m²/kg, 1298 m²/kg, and 827 m²/kg, respectively. The Water-to-Solid ratio (W/S) was 1.5, 2.0, and 2.5, respectively. The mass ratio of bentonite replacing partial cement was 0%, 5%, 10%, 15%, 20%, 25% and 30%. The water glass volume was 20% of the total volume of bentonite-cement slurry. All the experiments were carried out using tap water and at room temperature.

2.2 Experimental methods

Slurry A and Slurry B were prepared separately to avoid the rapid solidification between cement and water glass. Slurry A was the mixture of cement, bentonite, and water; Slurry B was the mixture of water glass and water. The mixture of bentonite and cement were stirred with water in a machine for about 3 minutes to make the slurry A, and water glass was diluted with water from 50 °Bé to 35 °Bé to make the slurry B according to Eqs. (1)-(2).

$$^{\circ}\text{Bé} = 145 - 145/d \quad (1)$$

$$V_w = V_b * (d_b - d_a)/(d_a - d_w) \quad (2)$$

Where, °Bé is the concentration of water glass, d is the density of water glass, V_w is the volume of water that

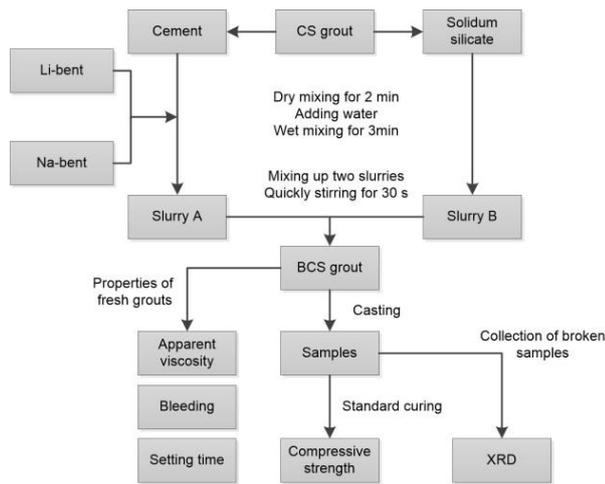


Fig. 2 Samples preparation steps

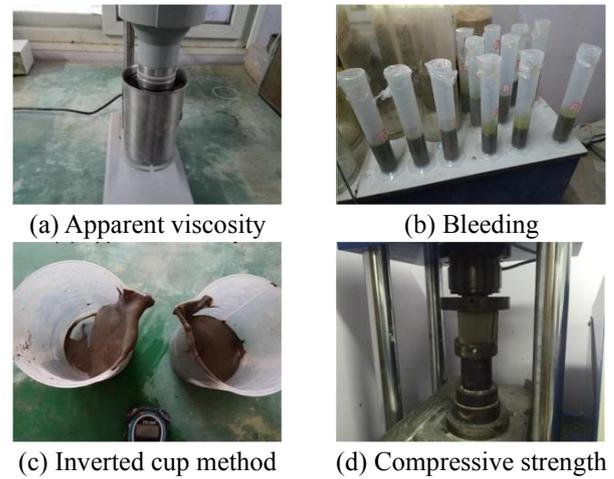


Fig. 3 Experimental methods and devices

needs to be added, V_b is the volume of water glass before dilution, d_b and d_a is the density of water glass before and after dilution, d_w is the density of water.

Similar to the operation steps of two-component grouting methods used by Liu and Chen (2019), the preparation steps of samples are shown in Fig. 2. All experiments were repeated three times. The specific test methods for fresh and hardened grouts were as follows:

Apparent viscosity test: The apparent viscosity of fresh BCS grout was determined by the ZNN-D6 rotary viscometer (China, Fig. 3(a)) according to GB/T 5005 (GB/T, 2010). It is based on the principle of measuring the rate of rotation of a solid shape (Viswanath *et al.* 2007). The 1/2 value of the reading at 600 rpm speed of viscometer (Zhou *et al.* 2018) was taken as the apparent viscosity of the slurry.

Bleeding test: The bleeding capacity of grout is an indicator of the stability of grouts. The bleeding was tested by gravity sedimentation in cylinders (Fig. 3(b)). 250 mL BCS grout was poured into a measuring cylinder and covered by a polyethylene film to prevent water evaporation (Massoussi *et al.* 2017), after 2 hours, the volume of upper clear liquid was recorded. The bleeding was the percentage of value recorded/250 mL (Sha *et al.* 2018).

Setting time test: Slurry A and slurry B were poured into two plastic cups, respectively. The slurry A was poured into slurry B first, and then the mixtures were poured into the other cup. The above operation was repeated until the mixtures lost fluidity. This method was known as the inverted cup method (Sha *et al.* 2018), see Fig. 3(c).

Compressive strength test: Slurry A and slurry B were mixed together and stirred for 30 s. After mixing evenly, the grouts were poured into $70.7 \times 70.7 \times 70.7 \text{ mm}^3$ ($2.8 \times 2.8 \times 2.8 \text{ in.}^3$) molds and cured in the conditions of $20 \pm 2^\circ\text{C}$ and 95% relative humidity until testing. The samples were cured for 1 day (1 d) and 3 days (3 d), and then they were tested according to GB/T 17671 (GB/T, 1999) by using a 200-kN BSRD-2015 homogenization testing machine (China, Fig. 3(d)). The load was continuously applied at a steady rate of 7.0 kN/s until failure occurred.

X-ray diffraction (XRD) testing: XRD analysis has been extensively applied to identify the components of cement hydration products (Wang *et al.* 2019). The absolute alcohol was used to terminate the hydration of samples. After 24 hours of soaking, these pieces were dried in a drying oven. Finally, the dried pieces were ground to a powder and stored in sealed bags to prevent carbonation and hydration (Kaminskas *et al.* 2015). The XRD patterns were recorded over a 2θ range from 3° to 70° at a resolution of $0.02^\circ/\text{step}$ on a diffractometer (Rigaku D/max, Tokyo, Japan).

3. Results and discussion

3.1 Apparent viscosity

Viscosity is a basic feature of all liquids and is the result of the internal resistance to flow or shear (Viswanath *et al.* 2007). It is a measure of the frictional properties of liquid and determines the flowability, pumpability, and injectability of grouts (Li *et al.* 2019, Viswanath *et al.* 2007). The apparent viscosity of BCS grout is plotted as increasing Li-bent and Na-bent substitutes, see Figs. 4(a)-(b).

As the W/S ratio increased, the viscosity decreased because more free water resulted in the smaller friction among solid particles (Deng *et al.* 2014). Therefore, on the basis that the slurry satisfies other engineering properties, the W/S ratio can be appropriately increased to improve fluidity and pumpability. Increasing the W/S ratio also helps to reduce the number of materials used, saving resources and cost.

As the amount of bentonite increased, the BCS grout became thickened regardless of whether Li-bent or Na-bent was added. Bentonite has a thickening effect because of its unique layer structure and good ion-exchange capacity (Günister *et al.* 2004). After the bentonite was added to the cement slurry, the bentonite was dispersed in the water to form a network structure in which free water was incorporated (Zhang *et al.* 2018), thereby increasing the viscosity.

The thickening effect of Li-bent was better than that of

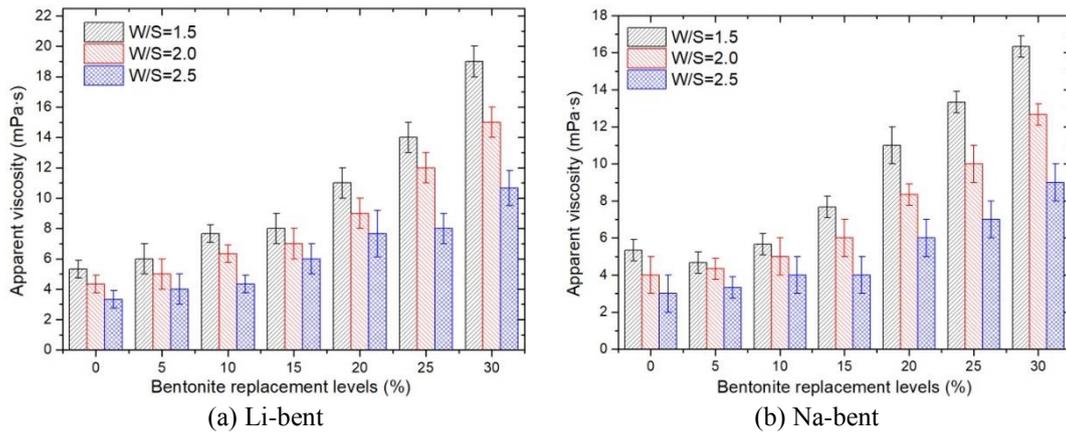


Fig. 4 The apparent viscosity of BCS grout containing different bentonites

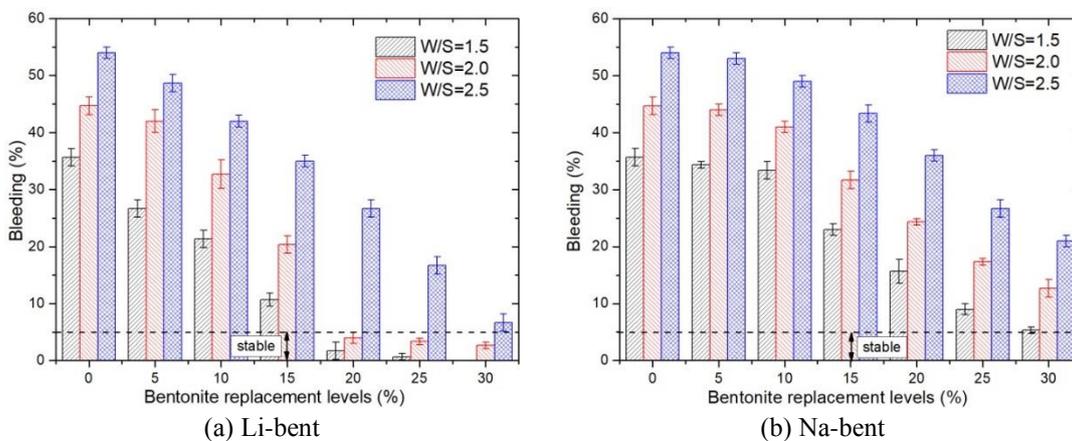


Fig. 5 The bleeding of BCS grout containing different bentonites

Na-bent. For example, at a W/S ratio of 1.5, the viscosity of BCS grout was increased by 60% and 20%, respectively, when 10% of Li-bent and Na-bent were respectively added. This may be related to the types of ions carried by bentonite. Essington (2003) summarized the relationship between enthalpy change (ΔH_h) and hydration degree, and found that the larger the negative value of ΔH_h , the greater the degree of ion hydration. The ΔH_h of Li^+ and Na^+ is -515 kJ mol^{-1} and -405 kJ mol^{-1} , respectively, which means that the hydration degree of Li^+ is greater than that of Na^+ . Thus, the more water molecules were strongly attracted by Li^+ compared to Na^+ , which reduced free water and increased the friction among solid particles. However, the range of viscosity changes was not much different. When the W/S ratio was 1.5, 2.0, 2.5, the viscosity of slurry A containing Li-bent changed within the range of 5–19 mPa·s, 4–15 mPa·s, 3–10 mPa·s (Fig. 4(a)) and the viscosity of slurry A containing Na-bent changed within the range of 5–16 mPa·s, 4–13 mPa·s, 3–8 mPa·s (Fig. 4(b)).

3.2 Bleeding

The bleeding is an index to evaluate the stability of the cement grains suspended in water (Massoussi *et al.* 2017). The bleeding of BCS grout was given in Figs. 5(a)–(b).

As the W/S ratio increased, the bleeding increased because more free water weakened the connection among

solid particles, which allowed free water to bleed through the weak junction of the solid particles. Massoussi *et al.* (2017) divided the kinetics of bleeding into three regimes: 1) an induction period exhibiting low water extraction velocity; 2) an extraction period exhibiting a more or less constant water extraction velocity; and 3) a consolidation decelerating regime, in which the cement grains is no longer affected by gravity. He believed that the bleeding was caused by the formation of preferential water extraction channels in the pastes. Herein, the channels refer to the weak junction of the solid particles.

As the amount of bentonite increased, the bleeding of BCS grout decreased regardless of the type of bentonite was added. This means that the stability of slurry A was improved by the addition of bentonite, which is consistent with the findings of Sha *et al.* (2018). The fresh grout is stable when its bleeding is less than 5% after 2 h from preparation (Li *et al.* 2017, Pantazopoulos *et al.* 2012). Therefore, the BCS grout was stable when the content of Li-bent was more than 20% at the W/S ratio of 1.5 and 2.0 (Fig. 5(a)). The BCS grout was not stable when the Na-bent was added less than 30% at these high W/S ratios (Fig. 5(b)). Higher content of more than 30% may be required to obtain the stable slurry at a high W/S ratio when Na-bent was added. But this will increase the viscosity of BCS grout and affect the fluidity and the injectability of grouting. It is a challenge to meet both the fluidity and stability of the

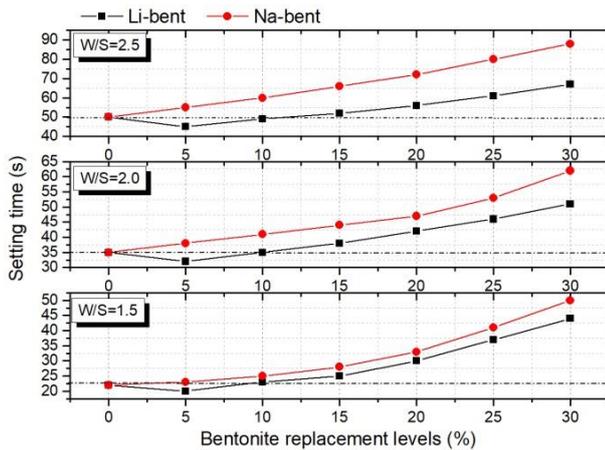


Fig. 6 The setting time of BCS grouts

grout. In engineering applications, the stable slurry is more versatile because it can be injected into deeper target fractures without bleeding.

The stabilizing effect of Li-bent was better than that of Na-bent. Similar to the kinetics of the thickening effect, this may also be related to the types of ions in bentonite. Compared with Na^+ , the strong hydration ability of Li^+ could combine more free water, so that the connection between solid particles and water molecules was tighter, thereby reducing the bleeding value.

3.3 Setting time

The setting time is the hardening parameter of grouts (Viktor and Galyna 2017), which determines their diffusion range and the depth of injection. The setting time of grouts containing different bentonites and W/S ratios is present in Fig. 6.

As the W/S ratio increased, the setting time prolonged, this is due to the dilution effect caused by free water. Water diluted the concentration of BCS grouts, reduced the contact of solid particles, and slowed down the reaction among particles.

As the bentonite content increased, the setting time became longer (except that 5% of Li-bent was added). This means that the setting time of BCS grouts can be prolonged by changing the content of bentonite, and this may be due to the bentonite delayed or disturbed the normal gelation process of effective hydration products (such as CSH gels) (Sha *et al.* 2018). In addition, the hydration of cement is from the outer layer to the inner layer (Scrivener and Nonat, 2011), and the average particle sizes of Na-bent, Li-bent, and cement are $1.782 \mu\text{m}$, $3.757 \mu\text{m}$, and $4.925 \mu\text{m}$, respectively (Fig. 1). Thus, the smaller particles of bentonite may cover the surface of the cement and hindered the cement hydration.

A comparison of the two bentonites shows that the setting time of Li-bent was shorter than that of Na-bent because Na-bent has the smallest average particles that adhered to the surface of the cement particles and hindered the hydration of cement. Moreover, Fig. 6 shows that 5% of Li-bent shortened the setting time of BCS grouts. This may be related to the concentration of Li^+ by cation exchange of

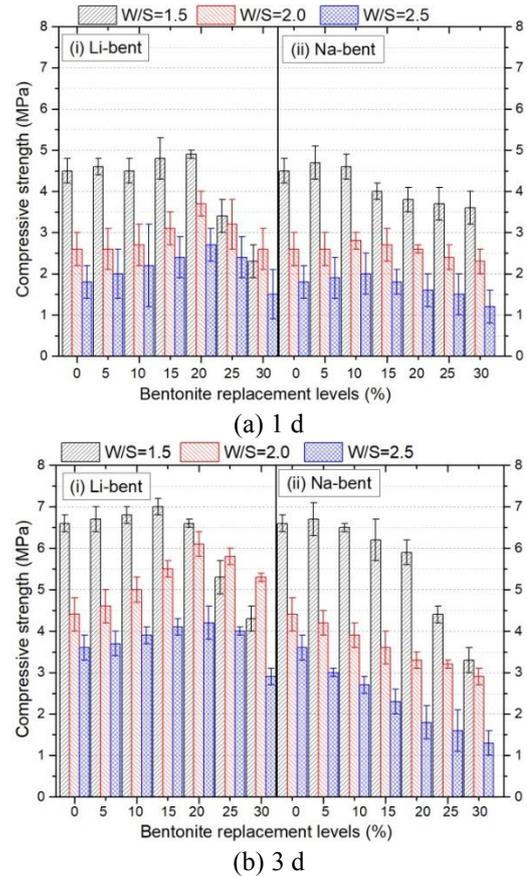


Fig. 7 The compressive strength of BCS grouts curing for (a) 1 d and (b) 3 d

Li-bent. Research has shown that the small radius of Li^+ has a good destructive effect on the protective film formed by cement hydration (Wang *et al.* 2018), which accelerated the hydration of cement (Juilland *et al.* 2010), thereby shortening the setting time.

3.4 Compressive strength

Compressive strength affects the reinforcement effect of grouts. Figs. 7(a)-(b) show the compressive strength of BCS grouts curing for 1 d and 3 d. In all mixtures, the compressive strength increased with extended curing time, and this is consistent with the results of Zhao *et al.* (2019). For example, the compressive strength of hardened BCS grout with 20% of Li-bent and W/S ratio of 1.5 was 4.9 MPa at 1 d and increased to 6.6 MPa at 3 d.

As the W/S ratio increased, the strength decreased. Similar to the mechanism of prolonging the setting time, the dilution effect caused by water played a major role in reducing strength.

As the bentonite content increased, the variation of compressive strength of BCS grouts after adding Li-bent and Na-bent was greatly different. In Fig. 7(a), when the dosage of Na-bent was less than 10%, the 1-d strength of BCS grout increased slightly. When the W/S ratio was 1.5, 2.0, and 2.5, the strength was increased by 4.44%, 7.69%, and 11.11%, respectively. This means that Na-bent enhanced the strength under a higher W/S ratio. Then as the

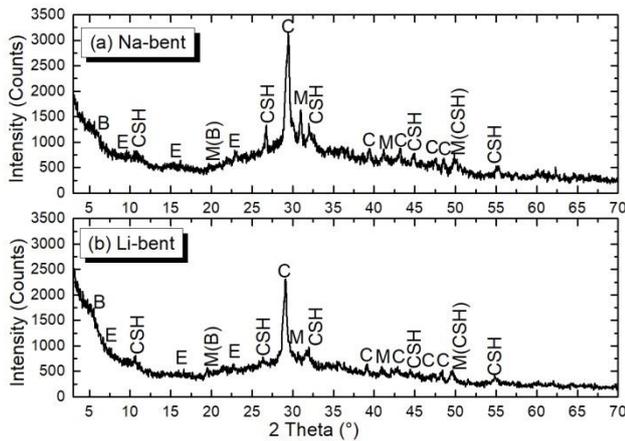


Fig. 8 The XRD spectra of hardened BCS grouts with (a) Na-bent and (b) Li-bent curing for 3 d (C: calcite, E: ettringite, M: monosulphoaluminate, B: bentonite, CSH: calcium aluminum silicate hydrate)

Na-bent content increased, the strength of BCS grouts gradually decreased. In Fig. 7(b), as the amount of Na-bent increased, the 3-d strength gradually decreased. In short, the Na-bent had a positive effect on the early strength (1 d) of BCS grouts under the conditions of small dosage (<10%) and high W/S ratio (>2.0), but it had an adverse effect on the long-term strength (3 d).

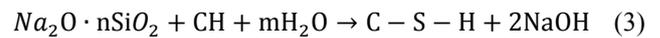
In Figs. 7(a)-(b), when the dose of Li-bent was less than 20%, the 1-d and 3-d strength of BCS grout gradually increased, and the maximum values of strength basically at 20% of Li-bent was 4.9 MPa, 3.7 MPa, and 2.7 MPa respectively curing for 1 d, and 7 MPa (15% of Li-bent), 6.1 MPa, and 4.2 MPa respectively curing for 3 d. After that, the strength decreased rapidly, especially when the W/S ratio was 1.5, the strength decreased by 53.06% and 34.85% when the dosage changed from 20% to 30%. In addition, 20% of Li-bent was most beneficial for strength improvement, when the W/S ratio was 2.0, the strength was increased by 42.31% (1 d) and 38.64% (3 d), respectively compared to that of the same ratio of CS grout without bentonite. In brief, Li-bent played a great important role in increasing the strength, and the enhancing effect was related to its amount. From the perspective of the reinforcement effect, Li-bent was superior to Na-bent.

3.5 XRD analysis

For the sake of comparison, two samples of Li-bent and Na-bent at the same ratio after 3-d curing were chosen and ground. The two samples were the ratio of 20% of bentonite, 20% of the water glass, and at the W/S ratio of 2.0, which were named Sample Na-bent and Sample Li-bent. X-ray diffractometers and software MDI Jade 6.0 were used to detect and analyze the different effect bentonites on the hydration products of BCS grouts. The results are displayed in Figs. 8(a)-(b).

The BCS grouts consisted of bentonite, cement, and water glass. There are four reactive phases in cement, namely, calcium silicate phases (C_3S and C_2S), aluminate phase (C_3A), and ferrite phase ($C_2(A, F)$), are hydrated

(Scrivener and Nonat 2011) and the main hydration products are hydrated calcium silicates (C-S-H), portlandite (CH), ettringite (AFt) and monosulphoaluminate (AFm). There are three stages for the hydration of bentonite, i.e., surface energy hydration, cation hydration and osmotic hydration (Huang *et al.* 2016). There is a pozzolanic reaction between cement and water glass to form C-S-H (Acevedo-Martinez *et al.* 2012, Kazemian *et al.* 2011), see Eq. (3), and between cement and bentonite (Wong *et al.* 2013).



As shown in Fig. 8(a)-(b), the hydration products are calcite, ettringite, bentonite, calcium aluminum silicate hydrate, and monosulphoaluminate, most of which were the same as those in pure cement. But there was no portlandite, a common product from cement hydration, because of the pozzolanic reaction between cement and water glass, and between cement and bentonite. The peak intensity of calcium was dominant because ground limestone was added as a minor ingredient in the cement or to an unavoidable carbonation process (Boháč *et al.* 2014). The hydration products of two samples were the same, while the peak intensity of CSH gel in Sample Na-bent (Fig. 8(a)) was relatively larger compared to that in Sample Li-bent (Fig. 8(b)). The CSH gel was the main contributor to the strength development of cement (Baquerizo *et al.* 2015). However, the strength of Sample Na-bent was 1.9 MPa lower than Sample Li-bent. It might be that CSH gel formed by Li-bent was amorphous and cannot be detected by XRD. From the inert filling effect view, the particles of Na-bent were finer than Li-bent, which was beneficial to improving the strength of BCS grouts. But this is contrary to the experimental results. Thus, further research is needed on the reasons why Li-bent increases the strength of BCS grouts.

4. Conclusions

The engineering properties of sodium bentonite (Na-bent) and lithium bentonite (Li-bent) as a partial substitute of cement in Cement-Sodium silicate (CS) grout were investigated in this paper. And a new grout bentonite-cement-sodium silicate (BCS) grout was obtained.

The following conclusions can be obtained:

- The best composition of BCS grout for commercial use was 2.0 of W/S ratio, 20% mass of Li-bent, 80% mass of cement, and 20% volume of water glass. And its viscosity was 9 mPa·s, bleeding was 5%, setting time was 42 s, as well as 1-d and 3-d compressive strength was 3.7 MPa and 6.1 MPa, respectively.
- Both Na-bent and Li-bent can be used as a partial substitute for cement in CS grout, which reduced carbon dioxide emissions by reducing the consumption of cement and improved the performance of CS grout. They are potential supplementary cementitious materials for CS grout.
- Unsurprisingly, the high W/S ratio increased the amount of free water, which resulted in a decrease in apparent viscosity and strength, and an increase in bleeding and setting time. The W/S ratio can be

appropriately increased to improve fluidity and the pumpability of grouts.

- Bentonite was beneficial for the stability of BCS grout, while a high substitution level (>20%) of bentonite had an adverse effect on the strength of hardened BCS grouts. The setting time of grouts was controllable by adjusting the level of substitution of bentonite. In addition, bentonite had a thickening effect on BCS grout.

- The effect of bentonite on the strength of BCS grouts was related to the type and substitution level of bentonite. When the replacement percentage of Na-bent was less than 10%, the early strength (1 d) of BCS grouts increased, but it had an adverse effect on the long-term strength (3 d) of BCS grouts. When the replacement percentage of Li-bent was 20% and 2.0 of the *W/S* ratio, the strength value of BCS grout was increased by 42.31% (1 d) and 38.64% (3 d) compared to CS grout.

- X-ray diffractometer analysis showed that the hydration products of BCS containing Na-bent and Li-bent were not much different. The hydration products are calcite, ettringite, bentonite, calcium aluminum silicate hydrate, and monosulphoaluminate, most of which were the same as those in pure cement.

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