The compatibility of bentonite/sepiolite plastic concrete cut-off wall material

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HIGHLIGHTS

- Fibrous and smectite clay groups are typical clay minerals corresponding to high plasticity index, adsorption water, adsorption ions compared to kaolinite and illite clay groups.
- Sepiolite, as a new clay resource in plastic concrete, was tested to determine if it is a replaceable material for cutoff walls due to its low permeability, mild swelling and normal strength.
- Sepiolite is comparable to concrete made with bentonite, which can be recommended under the condition of available sepiolite material and seepage water with high contamination.

ABSTRACT

Plastic concrete cutoff wall technology has been successfully applied to those water-control engineering projects with higher requirements for seepage control. The quantity and quality of clay, aggregate and cement, determine the appropriateness of plastic concrete. Therefore, in this study, laboratory tests of four diverse mix designs with bentonite and sepiolite clay materials were conducted to determine the most suitable material for concrete. By increasing the clay and cement content, a change was observed in the specimen properties; this change became more obvious with increase in specimen age. By increasing the silt and clay content, there was a noticeable reduction in compressive and tensile strength. The mechanical properties variation of concrete produced with sepiolite is comparable to concrete made with bentonite, which can be recommended under the condition of available sepiolite material and seepage water with high contamination. The improvement and modification of physical specifications of plastic concrete, such as strength permeability and metal adsorption, reduced cracks and increased the operating life of concrete for a variety of engineering structures.

1. Introduction

Plastic concrete has a higher formability, but lower compressive strength and permeability, resulting from the usage of clay slurry in the concrete mix design [17]. Plastic concrete consists of aggregate, cement, water, and bentonite clay mixed at a high water cement ratio to produce a ductile material than conventional structural concrete [17]. Plastic concrete shows great promise for satisfying the strength, stiffness, and permeability requirements for remedial cutoff wall construction [18]. Since the wall in its simplest structural form is a rigid diaphragm, deformations of earth embankment due to increase in reservoir level or seismic activity could cause its rupture, which would greatly decrease the flow efficiency of the cutoff wall and jeopardize the safety of the dam. Deformations of earth embankments due to fluctuations in impounded reservoir levels or seismic activity can cause concrete cutoffs to develop cracks. New leakage problems may then develop through these cracks, producing an inefficient cutoff [18]. In response to this dilemma, engineers have used plastic concrete to construct cutoff walls which have deformation characteristics similar to dam embankment soils [15].

Plastic concrete is also used to control the infiltration of harmful sewage and the penetration of seawater, and more recently for filling the surrounding water ducts in power plants [23]. Furthermore, the long-term stability of both requirements is often not guaranteed. Chemical incompatibility often creates an increase in permeability in conventional clay liners and clay–cement mixtures of cut-off walls [38].
In the selection of material type and in designing the mix of plastic concrete, many parameters, such as amounts, elasticity modulus, compressive strength, permeability, slump and density, play important roles. A change in any of these parameters from the design specification can affect the resulting concrete. For instance, reducing elasticity modulus and increasing flexibility, results in the reduction of compressive strength. Therefore, their values should be chosen within a confined range that results in the best desired concrete. On the other hand, a minimal strength values should be chosen within a confined range that results in the reduction of compressive strength. Therefore, their instance, reducing elasticity modulus and increasing flexibility, the design specification can affect the resulting concrete. For the purpose of increasing flexibility in the concrete, higher slump is needed in the mix design. Based on ICOLD’s suggestion [17], the plastic concrete mix design should have a permeability coefficient within the range of $10^{-5}$–$10^{-9}$ m s$^{-1}$ and a slump within the range of (10–22) cm.

Bentonites have so far, been defined and used for sealing purposes in civil and hydraulic engineering for a long period of time [4,13,22,28,37,23,31,40,6,12]. In all applications, clay minerals are functional and are not just inert components of the system. Having said that, it is known that fibrous clay minerals (Sepiolite) with typical structure and intermediate of kaolinite and montmorillonite characteristics are interesting clay resources, for the investigation of different mix designs.

Sepiolite, a needle like and fibrous clay mineral, belongs to the phyllosilicate group of 2:1 clay minerals which is widely distributed in soils and sediments of arid and semi-arid regions (precipitation less than 400 mm/year)[1,36]. Sepiolite minerals have unique characteristics, such as porosity, high specific surface, strong adsorptive and rheological properties, due to their structural characteristics [14]. These properties give sepiolite a broad range of applications such as viscosity builders in saltwater or high-electrolyte content drilling muds, and as an adsorbent of different materials from diverse environments [26].

Therefore, this research was conducted to (1) determine new plastic concrete formulas with other types of cementious binders through the addition of other mineral compounds such as sepiolite to the slurry material; (2) calculate the properties of concretes with different mix designs, in order to evaluate the effect of fine and coarse aggregates, cement and clay dosage as characteristics of concrete.

2. Materials and methods

2.1. Materials

Since the plastic concrete is made up of cement, aggregates, fine soil particles, and water, the used materials are thus described as follows:

2.1.1. Cement

Based on Portland cement types, ASTM C150, Type II (Moderate Sulfate Resistance) was used for all mixtures. The chemical analysis of cement is shown in Table 1.

<table>
<thead>
<tr>
<th>Cement</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>Fe$_2$O$_3$</th>
<th>CaO</th>
<th>MgO</th>
<th>SO$_3$</th>
<th>LOI*</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type II</td>
<td>21.90</td>
<td>5.09</td>
<td>3.90</td>
<td>62.40</td>
<td>1.90</td>
<td>1.83</td>
<td>1.40</td>
<td>98.42</td>
</tr>
</tbody>
</table>

Fig. 1. Particle size distribution of aggregates.

2.1.2. Aggregates

Alluvial material with good roundness was used as aggregate, which consisted of sand ($0.075 \text{ mm} < D < 4.76 \text{ mm}$) and gravel ($4.76 \text{ mm} < D < 19 \text{ mm}$).

Four different aggregate mix designs were compared based on the effect of aggregate grading on the mechanical properties of plastic concrete. Fig. 1 shows the particle size curve of the four different aggregate mix designs.

2.1.3. Fine soil particles

2.1.3.1. Silt. Silt with a diameter of less than 0.075 having no plasticity was used.

2.1.3.2. Clay. Clayey materials were chosen from two different clay groups: Montmorillonite (Bentonite soil) and Fibrous (Sepiolite soil).

2.1.3.2.1. Mineralogy. The most common method of identifying clay minerals is X-ray diffraction [25]. To determine the mineral purity reservoirs and the composition of mineral deposits, powder samples were prepared and studied using X-ray diffraction.

A Philips X-ray diffractometer (Model PW 1840-Copper target) was used to record diffractograms between 4 and 70° (20). Figs. 2 and 3 show the main minerals of sepiolite (based on the report by Hojati and Khademi [14] and bentonite soils, respectively.

2.1.4. Water

Laboratory tap water with electrical conductivity of 1.2 dS m$^{-1}$ and hardness of 85 ppm was used for producing all plastic concretes.

2.2. Mix design

2.2.1. Mixing procedure

The dry materials (sand, gravel, silt, and clay soil) were weighed based on the mix proportions shown in Table 2. However, 0, 20, 40 and 60% clay were added to the mixtures as treatments. According to recommendations of the International Committee on Large Dams (ICOLD) [16], Sepiolite and bentonite powder were added to the water and stirred for 1–2 min. Thereafter, the mixture was kept for 24 h to complete water adsorption and swelling. Cement
and other additives were added to the mixture and blended for 5 min to form a plastic concrete. A summary of the method of mixing materials of plastic concrete is shown in Fig. 4. Duplicate samples were prepared for different tests evaluation.

The backfill materials for plastic concrete should have a slump between 100 and 220 mm, in order to achieve optimum workability and smooth consistency, in accordance to ICOLD [17]. In this research, water was added to achieve a standard slump within the range of (190–200) mm. Slump was measured as follows (1):

\[
\text{Slump} = \text{hm} - \text{hs}
\]

\[ \text{Slump} = hm - hs \]

In this research, the slump of plastic concrete was measured using the following formula:

\[ \text{Slump} = \text{hm} - \text{hs} \]

The required amount of water was weighted and slowly added to the dry material while blending by hand, until a homogeneous mixture was achieved. After mixing, cubic (100 * 100 * 100 mm) and cylinder (150 * 200 mm) samples were prepared and cured for the specified period (7, 28 and 90 days) in an open water bath area in the laboratory at a temperature between 20 and 25 °C. Cubic samples were designed for compressive strength and cylinder samples for water penetration depth and tensile strength.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Aggregates</th>
<th>Silt (kg)</th>
<th>Cement (kg)</th>
<th>Clay type</th>
<th>Mean water (L)</th>
<th>Curing time (Day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix1-C</td>
<td>320</td>
<td>1280</td>
<td>225</td>
<td>200</td>
<td>325</td>
<td>7–28–90</td>
</tr>
<tr>
<td>Mix1-B</td>
<td>305</td>
<td>1295</td>
<td>225</td>
<td>200</td>
<td>390 (Bentonite)</td>
<td>7–28–90</td>
</tr>
<tr>
<td>Mix1-S</td>
<td>305</td>
<td>1295</td>
<td>225</td>
<td>200</td>
<td>444</td>
<td>7–28–90</td>
</tr>
<tr>
<td>Mix2-C</td>
<td>305</td>
<td>1295</td>
<td>200</td>
<td>280</td>
<td>330 (Bentonite)</td>
<td>7–28–90</td>
</tr>
<tr>
<td>Mix2-B</td>
<td>305</td>
<td>1295</td>
<td>200</td>
<td>280</td>
<td>420 (Bentonite)</td>
<td>7–28–90</td>
</tr>
<tr>
<td>Mix2-S</td>
<td>305</td>
<td>1295</td>
<td>200</td>
<td>280</td>
<td>500 (Sepiolite)</td>
<td>7–28–90</td>
</tr>
<tr>
<td>Mix3-C</td>
<td>830</td>
<td>930</td>
<td>180</td>
<td>290</td>
<td>7–28–90</td>
<td></td>
</tr>
<tr>
<td>Mix3-B</td>
<td>830</td>
<td>930</td>
<td>180</td>
<td>290</td>
<td>7–28–90</td>
<td></td>
</tr>
<tr>
<td>Mix3-S</td>
<td>830</td>
<td>930</td>
<td>180</td>
<td>290</td>
<td>7–28–90</td>
<td></td>
</tr>
<tr>
<td>Mix4-C</td>
<td>830</td>
<td>930</td>
<td>180</td>
<td>290</td>
<td>7–28–90</td>
<td></td>
</tr>
<tr>
<td>Mix4-B</td>
<td>830</td>
<td>930</td>
<td>180</td>
<td>290</td>
<td>7–28–90</td>
<td></td>
</tr>
<tr>
<td>Mix4-S</td>
<td>830</td>
<td>930</td>
<td>180</td>
<td>290</td>
<td>7–28–90</td>
<td></td>
</tr>
</tbody>
</table>

* C: Control, B: Bentonite, S: Sepiolite, and Mix: Mixture.
2.3. Laboratory tests

2.3.1. Compressive strength

The unconfined compressive strength of concrete can reflect cement and pozzolanic activity, quality of the cement matrix and its continuity or aggregates. Although, plastic concrete cutoff walls do not require high strength, but it should to some extent, tolerate soil lateral stresses both during implementation and operation. The concrete compressive strength of the cubic samples was tested over a curing period of 7, 28 and 90 days based on the standard procedure of (ASTM C109) with loading speed of 0.3 MPa s\(^{-1}\). The compressive strength was tested on 168 cubic concrete samples (24 control samples, 72 sepiolite-plastic concrete, and 72 bentonite-plastic concrete).

2.3.2. Tensile strength

Indirect tensile strength was performed on standard square-shaped samples (10, 100 and 200 mm) according to ASTM C496 Splitting method (Brazilian) during the curing period of 28 and 90 days. The tensile strength was tested on 112 cylindrical concrete samples (16 control samples, 48 sepiolite-plastic concrete, and 48 bentonite-plastic concrete).

In this experiment, the sample was placed horizontally and the P force entered until the sample was broken (Fig. 5). The tensile strength of the concrete was obtained as shown in Eq. (2):

\[
F = \frac{2P}{\pi DL}
\]

F: Crevice corrosion resistance of concrete, D: Diameter cylindrical, L: Height of cylinder, P: Force that causes the sample slot.

2.3.3. Water penetration depth

After curing for 28 and 90 days, the cylindrical specimens were selected for testing water penetration rate. In this test, the upper surface of the concrete (the surface exposing to water) was roughed by a wire brush, and then a 10 cm water height was allowed to stay on the concrete for 3 days (72 h). After exceeding the specified time, specimens were split for measuring the water penetration depth. The water penetration depth was tested on 112 cylindrical concrete samples (16 control samples, 48 sepiolite-plastic concrete, 48 bentonite-plastic concrete).

2.3.4. Metal adsorption

In order to check the cation adsorption capacity of the used clays in plastic concrete, a batch process method was performed as follows:

- **Chemical materials:** CdCl\(_2\)·6H\(_2\)O and CaCl\(_2\) were used as adsorbent and electrolyte materials, respectively.
- **Preparation of adsorbents:** Air dried Sepiolite and bentonite were grinded and sieved (mesh number 200) to make a uniform compound.
- **Preparation of 1\% suspension of adsorbate and absorbent:** About 0.1 g of each clay particles (adsorbent) were weighted and transferred to centrifuge tubes, then 10 cc of cadmium solution with different concentrations was added to each sample.
- **Adsorption experiment:** A suspension of 1\% absorbate (Sepiolite/Bentonite) and adsorbate (0.01 M CaCl\(_2\) solution containing Cd (II) chlorides at several different concentrations; 10, 50 and 100 mg L\(^{-1}\)) in three replicates for each concentration, were shacked for 24 hat ~25 °C in constant phs. Shacked samples were centrifuged and Cd was measured in the supernatant using Atomic Absorption Spectroscopy (AAS-Graphite Furnace GF 3000, GBC) Instrument. The concentration of adsorbed cadmium (Q) was determined by the difference between the initial concentration in the aqueous solution and that in the supernatant [8]:

![Fig. 4. The schematic way of mixing materials of plastic concrete.](image)

![Fig. 5. Tensile strength samples after splitting.](image)
$Q = (C_0 - C_e)V/W$  \hspace{1cm} (3)

where $C_0$ and $C_e$ are the initial and equilibrium liquid-phase concentrations of metal ion solution (mg L$^{-1}$), respectively; $V$ is the volume of metal ion solution (L), and $W$ is the mass of the clay (mg).

3. Results and discussion

3.1. Sepiolite and bentonite properties

The clay minerals, smectite and palygorskite-sepiolite, are among the world’s most important and useful industrial minerals. The important characteristics associated with the applications of clay minerals are particle size, shape, surface chemistry, surface area, surface charge, and other properties specific to particular applications, including viscosity, color, plasticity, green, dry and fired strength, absorption and adsorption, abrasion and pH. In all applications, clay minerals are functional and are not just inert components of the system [26].

Fibrous clay minerals are the main clay minerals commonly found in soils of arid and semi-arid regions. The percentage of fibrous clay mineral in soils is significantly related to the gypsum content and P/ET$^*$ of the soils. An increase in gypsum or decrease in P/ET$^*$ (or increase in aridity) would lead to higher levels of mineral in soils [21]. Therefore, the possibility of using fibrous clay minerals for engineering practices will increase in arid and semi-arid regions. The annual tonnages of palygorskite and sepiolite are estimated to be 1,300,000 and 850,000 tons, respectively. The United States is the largest producer of palygorskite and Spain is the largest producer of sepiolite. The largest reserves are in Anhui and Jiangsu Provinces in China [27]. Sepiolite is mined in The USA, Spain, Turkey, China, Italy, Somalia and somewhat sporadically in France, India, the Islamic Republic of Iran, Kenya, and the United Republic of Tanzania [9,7,27,11,14]. Sepiolite is rarely found in USSR and is probably not mined in that country [30].

Bentonite is a plastic clay generated frequently from the alteration of volcanic ash, and consists predominantly of smectite minerals, usually montmorillonite. Smeectite crystallites are three-layer clay minerals. They consist of two tetrahedral layers and one octahedral layer. Bentonites are valuable to a great variety of industries including electric, ceramics, painting, pharmaceuticals, cosmetics, filtering agents, household products and in particular detergents [3]. Sepiolite is lightweight, porous clay with a large specific surface area and has been shown to have a needle-like morphology. High surface area and porosity, as well as the unusual particle shape of this clay, accounts for its outstanding sorption capacity and physicochemical properties, which make it a valuable material for a wide range of applications [26]. For cut-off walls and liners, the adsorption ability, the ion exchange capacity, the swelling behavior, permeability, and durability of clay and plastic concrete are important Rodriguez-Navarro et al. [34] confirmed that the damage of Egyptian limestone sculptures, in which the clay fraction consisted mostly of sepiolite, was due to expansion (4.5%), X-ray diffraction (XRD) analysis of samples in contact with ethylene glycol (EG) and dimethyl sulfoxide (DMSO) showed the occurrence of crystalline swelling of sepiolite. Swelling also occurred due to hydration of the clay surfaces and also the electrostatic forces between clay particles, which was assumed to be promoted by the presence of Na counter ions in water solution.

In this study, tests were conducted on two types of locally available clayey soil in Iran (Bentonite and Sepiolite). Therefore, the existing types were selected and tests were performed according to the API 13A standards. Table 3 shows the main engineering characteristics of bentonite and sepiolite. As shown in Table 3, sepiolite and bentonite have outstanding properties, such as plasticity, surface area to tolerate deformations, and adsorption of water; although bentonite recorded higher swelling and plasticity as compared with the sepiolite clay groups. As a consequence, sepiolite and bentonite are almost similar in terms of physical properties; therefore, further investigation of sepiolite and bentonite is required to provide significant and major data for researchers and implementers. Since, plastic concrete walls must be resistant when subjected to earthquake loading. This requires that the wall be adequately deformable. Plastic concrete may be an appropriate material providing such deformability. To determine strength and deformation parameters of soils, i.e. clays, Atterberg limits are used to calculate the plasticity index or liquidity index. Analysis of factors affecting these limits has been the subject of numerous studies [24,20,35]. Based on sepiolite and bentonite characteristics (Table 3) and also W/F ratios (Table 4), plasticity index Ip, liquidity index LI or moisture content w% is high and almost similar rather than other clay minerals.

3.2. Compressive and tensile strength

As shown in Fig. 6, the 7 days compressive strength of plastic concretes with bentonite and sepiolite ranges from 0.98–9.8 MPa to 0.29–7.8 MPa, respectively; the 28 days compressive strength ranges from 2.06–10.7 MPa to 0.39–8.83 MPa, respectively; the 90d compressive strength ranges from 2.4–19.1 MPa to 0.78–14.1 MPa, respectively; the 28d splitting tensile strength ranges from 0.09–0.9 MPa to 0.03–0.7 MPa, respectively; and the 90d splitting tensile strength ranges from 0.19–1.1 MPa to 0.06–1.0 MPa, respectively (Fig. 7).

In general, the lowest strength was seen after 7 days curing as compared with 28 and 90 days curing, while 90 days curing specimens exhibited the highest strength. The strength of plastic

| Table 4 |
| Water to fine particle ratio in four different mix designs. |
| Treatment* | Mix1 | Mix2 | Mix3 | Mix4 |
| W/F/# | C-0 | B-20 | B-40 | B-60 | S-20 | S-40 | S-60 | S-60 |
| W/F | 1.63 | 1.78 | 1.98 | 2.07 | 1.84 | 2.16 | 2.6 |
| Treatment | C-0 | B-20 | B-40 | B-60 | S-20 | S-40 | S-60 |
| W/F | 1.17 | 1.29 | 1.48 | 1.72 | 1.48 | 1.79 | 2.05 |
| Treatment | C-0 | B-20 | B-40 | B-60 | S-20 | S-40 | S-60 |
| W/F | 0.74 | 0.9 | 1.06 | 1.4 | 1.06 | 1.32 | 1.35 |
| Treatment | C-0 | B-20 | B-40 | B-60 | S-20 | S-40 | S-60 |
| W/F | 0.7 | 0.76 | 0.9 | 1.08 | 0.85 | 0.9 | 1.2 |

* C: Control, B: Bentonite, S: Sepiolite, and Number: Clay percent.
# Water to Fine particle ratio.
concrete increased with increase in curing age (its curing age is extensive). The strength of plastic concrete with a curing age of 28 days can achieve 40–60% of the plastic concrete strength [15]. Increasing the clay dosage decreased the compressive strength (Fig. 6) and tensile strength (Fig. 7) in all curing time. Based on the great attention given to plastic concrete cutoff wall technology in the 1980s, by the International Committee on Large Dams, it was pointed out that 28 days compressive strength should range from 1 to 5 MPa [16]. With regards to 28 days curing specimens, the plastic concretes of mix1, mix2, mix3 and mix4 were in the ideal range after the addition of 2, 40, 40 and 60% bentonite to the concrete mixture, respectively.

The ideal range for sepiolitic concrete was obtained by adding 20, 20, 40, and 40% fibrous clay to mix1, mix2, mix3 and mix4, respectively. Mix4 (1550 kg m\(^{-3}\) aggregates-280 kg m\(^{-3}\) cement) required more clay (60% bentonite/40% sepiolite) to gain useful strength for plastic concrete; in the case of few clay resources, its mixture design is not recommended as a good enough for plastic concrete. In a situation of good mixture design, such as good quality and quantity of aggregates and cement, it would be possible to gain the required compressive strength with fewer sepiolite clay amounts rather than the bentonite clay amount.

The tensile strength increased by increasing the duration of curing and decreasing the clay dosage (Fig. 7). The order of tensile strength was as Mix3-B > Mix3-S > Mix2-B > Mix2-S > Mix1-B > Mix1-S. Therefore, there was a significant difference among mixture design 1, 2 and 3, but the difference was not considerable between the bentonite and sepiolite treatments of each mixture design. Although, slightly more tensile strengths were observed for bentonite samples as compared with sepiolite samples.

Gao et al. [10] stated that tensile/compressive ratio (the ratio of tensile strength to compressive strength of the concrete with the

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Fig. 6. Compressive strength of bentonite and sepiolite plastic concrete with different curing time (7, 28, 90 days).
same composition: T/C) is an important indicator to evaluate the mechanical properties of the concrete. The higher the strength, the smaller the T/C ratio and the greater the brittleness. The T/C ratio of high-strength concrete is only 0.042–0.05. Based on the analysis of results in this research, the T/C ratio of plastic concrete ranged from 0.07 to 0.27, which is much larger than that of plain concrete and high-strength concrete, thus, reflecting the characteristics of a large deformation of plastic concrete.

3.2. Water to fine material ratio

The measured water to cement and clay soil ratio is shown in Table 4. The addition of sepiolite to plastic concrete and more clay content are the main factors of increasing water/fine material ratio. The results also indicated that the compressive and splitting tensile strengths of plastic concrete significantly reduce with increase in water-fine particles (Cement + Clay) ratio; the strength significantly decreases with increasing clay content. An increase in cement content, to some extent, could increase the bond strength between cementitious materials and aggregate. However, when the amount of gel paste is too high, the addition of clay could enhance the strength because clay soil has a large water absorption capacity. In general, the strength decreases with increasing water to fine particles, as more water will result in higher (capillary) porosity. Beside, very low water content would decrease the bond strength as the cement may not be able hydrate sufficiently, but such small amount of water is hardly used [5,10,29]. On the other hand, excessive fluid consistency may lead to segregation of the mixture and problems with strength. Also, the addition of too much plasticizer to obtain certain consistency, may lead to slower hydration and therefore, slower development of strength.

Eq. (4) can be used to determine the adhesive materials (cement + clay) to water content ratio in plastic concrete. Determination of the ratio is to seal the cutoff walls, in order to tolerate the hydraulic gradient caused by excess water.

$$\frac{(B+S)}{W} + C = \frac{1}{w} + \frac{(B+S)}{W}$$

where B and S are bentonite and sepiolite values, C is the amount of cement, and W is the water content.

3.4. Water penetration depth

Water penetration depth in concrete is affected by intrinsic characteristics of concrete material and discontinuities. Increasing colloidal agents, water to cement ratio, and use of suitable additives are among the main factors which reduce water penetration rate in concrete [32]. The effect of curing time (28 and 90 days) and type of clay (Bentonite and Sepiolite) on water penetration depth is shown in Table 5. As shown in the table, penetration depth decreased with increasing clay values and curing duration. Water penetration depth decreased significantly with increasing clay dosage from 0 to 20%; however, changes in declining penetration depth from 20 to 40 and 40 to 60% clay amount were not observed.

3.5. Mixture designs

As shown in Table 2, and Figs. 6 and 7, as cement increases, the strengths of concrete increased. Mix4 and mix3 and also mix1 and mix2 had almost the same aggregates (Fig. 1). Since more than fifty percent of the concrete is made of aggregates, its types, quality and general properties will determine the quality of the concrete [29]. A comparison between same mixtures with the same aggregates showed that increasing cement, increased the strength of concrete. On the other hand, the evaluation of different mixtures, such as mix1 and mix2 with mix3 and mix4, showed that the addition of silt could decrease strengths. Beside, as silt increases, strength decreased in mix 1 rather than mix 2.

3.6. Metal adsorption

The contamination of water resources by heavy metals is one of the environmental issues at the global level. Toxic heavy metals in groundwater and surface water are a risk to living organisms [39]. Studies have shown that some surface or underground water have contamination of 0.1–1 ppm Cd, in areas near polluted sources. There are various chemical and physical methods that can be used to remove cadmium from aqueous solutions [2,19,33].

In several practical cases and researches, the adsorption process has been shown to be a simple and useful strategy for water and wastewater treatment. In recent years, attention has shifted to the use of low cost absorbents, such as clay minerals, for the removal of heavy metals from water, they are termed natural
absorbs. In this study, the ability of two clay soils, bentonite and sepiolite, were investigated to evaluate the removal of toxic element, cadmium, from aqueous solutions.

Fig. 8 shows the adsorbed cadmium from aqueous solutions at different Cd concentrations by bentonite and sepiolite soils. Based on obtained data, at a concentration of 100 mg L\(^{-1}\) cadmium, bentonite and sepiolite were able to adsorbed 28.6 and 83.75 mg L\(^{-1}\) Cd from solution, but adsorption by sepiolite was much more than that of bentonite. In the comparison of adsorption of Cd from solutions with concentrations of 10–100 mg L\(^{-1}\) Cd, it was indicated that by increasing the initial concentration of cadmium, cadmium adsorption by the two clayey soils reduced due to the saturation of adsorption sites (Fig. 8).

4. Conclusions

Bentonite has been the only promising clay type for making plastic concrete with interesting durability, strength and permeability. Kaolinite and illite have been tested by several researchers, and have not been recommended as clay to build a favorable plastic concrete. In this study, Seepilite, as a new clay resource in plastic concrete, was tested to determine if is a replaceable material for cutoff walls due to its low permeability, mild swelling and normal strength.

Fundamentally, few amounts of sepiolite (~20%) may provide the required strength. Its water movement has not changed drastically as compared with bentonite. However, sepiolite could adsorb much more heavy metals because of its fibrous and network like structure. In conclusion, sepiolite could be used as clay proportion in the event that cement and aggregate content is appropriate. Also, its possibility to act as a replaceable material is excellent when compared with bentonite, especially in terms of treatment of contaminated seepage water such as tailing dams.

Furthermore, silt could be added to the mixture design as part of fine aggregates in order to provide normal strength and permeability of plastic concretes.

The compressive strength and splitting tensile strength of plastic concrete were significantly reduced with increase in water-cement ratio. The strengths increased with increase in cement content, but with slow growth rate. The appropriate amount of cement was obtained as 200 kg/m\(^3\); the strength significantly increased first and then decreased with increase in bentonite content. The properties of the specimens changes by increasing the clay content. It seems that this affection is more important as the age of the specimen increases.

The tensile/compressive ratio of plastic concrete is much larger than that of plain concrete and high-strength concrete, which reflects the characteristics of a large deformation of plastic concrete.

References
