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Expanded Clay Applications in Internal Curing of Concrete

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Internal curing is used to reduce shrinkage and early age cracking of poured concrete. The internal curing process depends on providing internal moisture to hardening concrete using prewetted light weight aggregates, as expanded slates and shales. The main objective of this research is to produce internally cured light-weight concrete mixes to be used in bridge deck construction. Light-weight mixes are developed by incorporating different percentages of pre-wetted expanded clays in partial replacement of mix coarse aggregates. Expanded clays will internally provide the concrete with adequate moisture to account for water evaporating during concrete hardening. Produced concrete mixes are characterized by light weight, comparable compressive strength, and reduced shrinkage and early-age cracking. Produced lightweight mixes showed comparable strength with minimized shrinkage, which will positively impact the durability of concrete

Keywords: Internal Curing, Shrinkage, Cracking, Expanded Clay, Expanded Shale

Introduction

According to the American Concrete Institute (ACI), curing is defined as " action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and (if applicable) pozzolanic reactions to occur so that the potential properties of the mixture may develop” (ACI, 2010). In current construction practices, two types of curing processes are used. First, external curing using external source of water, covering poured concrete with wet burlap, or spraying chemical compounds. Second, internal curing by providing extra source of water within the poured concrete. Internal water supply is usually provided by using pre-wetted light-weight aggregate in the concrete mix design. Curing process is mostly important for concrete at early age. When concrete mix is poured, hydration process of cement (and pozzolanic materials-if any) starts. The size of concrete resulting from the hydration process is smaller than the original size of poured concrete. This volume reduction results in early shrinkage and can potentially induce cracking throughout the poured concrete section (Bentz and Weiss, 2011).

The main objective of this research is to investigate the possible use of prewetted expanded clay in partial replacement of coarse aggregates to produce internally cured light-weight concrete mixes to be used in different construction applications, with special emphasis on pouring bridge decks, which is highly susceptible to cracking due to early-age shrinkage of concrete. Due to the expanded clay lower density, the final weight of developed mixes is lower as compared to conventional concrete mix designs. (refer to figure 1 for weight-to-volume ratio of different types of lightweight aggregates)

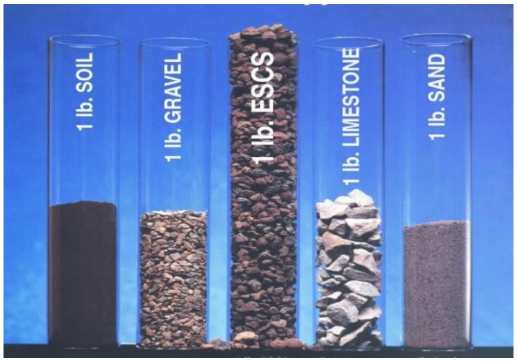

Figure 1. Lightweight aggregate (ESCS) volume vs. conventional aggregates

Advantages of Internal Curing of Concrete

The National Cooperative Highway Research Program (NCHRP) Synthesis states that the largest factors resulting in bridge deck cracking are weather and curing (NCHRP, 2004). Cracking is increased with higher temperature variations, lower moisture content of poured concrete, and higher water evaporation. Due to their high exposure to environmental conditions, bridge decks experience the highest evaporation rates, which results in a significant early age cracking of bridge decks. Internal curing of concrete results in a continuous flow of curing water to replace evaporation of moisture through the concrete surface. When compared to external curing, internal curing is advantageous due to providing the water internally and across the whole thickness of the poured structural member, while external curing only provides moisture through the outer surface of the poured member (see figure 2).

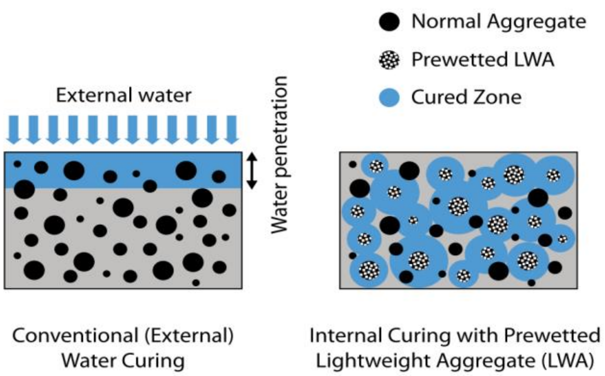

Figure 2. Internal curing versus external curing of poured concrete (Weiss et al., 2012)

Research showed that internal curing of conventional concrete mixes results in a 15% increase in the degree of hydration, and a significant increase in final compressive strength of developed concrete mixes (Espinoza-Hijazin and Lopez, 2011). Internal curing of concrete can be attained using saturated pre-wetted lightweight aggregates (Ghourchian et al., 2013, Bentz et al., 2005, Zhutovsky and Kovler, 2005, Akhnoukh, 2018, and Mousa et al., 2015). Other research projects utilized poly-glycol products in concrete mixing as an internal curing agent (El-Dieb, 2007, and Troli et al., 2005). Recently, different granular particles of micro and nano-size are used to develop mixes with higher mechanical properties as compared to conventional concrete mixes (Akhnoukh, 2013, Akhnoukh, 2019, and Akhnoukh and Elia, 2019). However, the possibility of internal curing of these mixes is not well-investigated. Thus, internal curing and its effect on mixes with higher compressive strength is investigated in this research project.

Research Objectives

The main objective of this research is to develop internal-cured lightweight concrete mixes to be used in pouring highway bridge decks. Mix design depends on incorporating pre-wetted lightweight expanded shales in partial replacement of regular-weight coarse aggregates. A minimum 24-hour compressive strength of 28 MPa (4,000 psi) and 28-day compressive strength of 42 MPa (6,000 psi) is targeted. Strain measured in developed mixes should not exceed 300 E-6 (300 micro-strain), which is the strain measured for control specimens produced with no internal curing agent.

Experimental Investigation

The experimental phase of this research project included two steps: first, a control mix was designed and poured using Type I/II Portland cement, and regular aggregates, second: coarse lightweight aggregate were used in partial/stepwise replacement of coarse aggregate to pour lightweight concrete mixes. Compressive strength and shrinkage of developed lightweight mixes are compared with properties of the control mix. Expanded clay was used as a lightweight coarse aggregate in this research (see figure 3)

Figure 3. Lightweight expanded clay

The lightweight aggregates used as an internal curing agent has a high voids ratio, high absorption capacity and low specific gravity (see table 1 for lightweight aggregates properties)

Table 1

Coarse aggregate properties

Coarse Aggregates	Absorption Capacity %	Specific Gravity %
Crushed Limestone	0.4	2.68
Expanded Clay	15.0	1.25

Prior to concrete mixing, the lightweight aggregates were submerged in water for 24 hours. Prewetted lightweight aggregates were used in mixing after removal from water to ensure the aggregate saturation. A total of 6 mixes were developed using lightweight aggregates and one mix was developed using normal weight aggregates as a control mix. Three lightweight mixes were developed using expanded clay in partial replacement of normal weight coarse aggregates. The amount of expanded clay used is 100, 200, and 300 lb./yd^3 respectively. The concrete mix designs for the lightweight and normal weight (control mix) had a water-cement ratio of 0.45 (see table 2 for mix designs).

Table 2

Concrete mix designs

Mix	Cement	Coarse Aggregate	Lightweight Aggregate	Sand	Water	Water/Cement
Control	610	1700	0	1440	270	0.45
Clay100	610	1600	100	1330	270	0.45
Clay200	610	1500	200	1220	270	0.45
Clay300	610	1400	300	1110	270	0.45

Concrete cylinders were cast for compressive strength testing according to ASTM C39, and concrete prisms were poured in accordance with ASTM C490. Concrete prisms were used to measure the linear length change according to ASTM C157

Results and Discussions

Compressive Strength

Compressive strength testing for control mix and lightweight aggregate mixes was conducted at ages of 1, 14, and 28 days. The recorded result for mix compressive strength is the average of 3 cylinders strength. Early strength of control specimen was lower than lightweight aggregate specimens. This is attributed to the positive effect of internal curing induced by the lightweight aggregates at early age of concrete, which altered the negative effect of micro cracking associated with cement hydration. However, the compressive strength results for poured specimens at ages of 7, 14, and 28 days showed that the control specimen has a higher compressive strength, as compared to lightweight aggregates specimens. This is attributed to the lower particle strength of expanded shales and clays (See figure 4 for compressive strength test results)

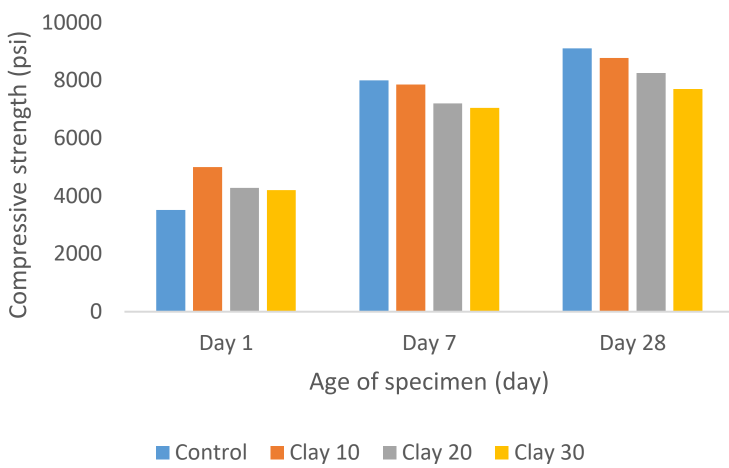

Figure 4. Compressive strength results of developed specimens

Shrinkage Test Results

Three concrete prisms are poured for each mix design. Average shrinkage of specimens is measured at ages of 1, 7, 14, 21, and 28 days (see figure 5 for shrinkage test measurements).

Figure 5. Concrete prism mold (left) and measurement of shrinkage (right)

The shrinkage test results show that the control specimen displays the largest shrinkage due to the absence of internal curing agents. The existence of prewetted and saturated expanded clay in the mix results in surplus mix moisture content which substitutes the lost moisture. Thus, shrinkage of concrete is reduced (see figure 6 for strain results due to shrinkage).

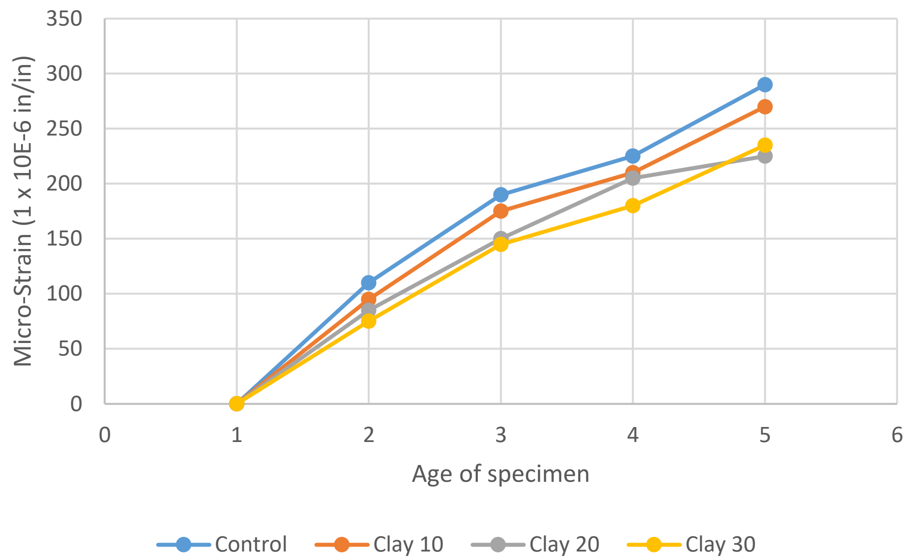

Figure 6. Strain results for control and lightweight aggregates specimens

Conclusions

The results of the experimental investigation showed that expanded clay can be successfully used as an internal curing agent in the mix development of internally-cured lightweight concrete mixes. Mixes developed using lightweight aggregates showed an improvement in early age (24-hour) compressive strength due to the positive impact of internal curing at early age of concrete. Final compressive strength of lightweight aggregate concrete is reduced due to the reduced strength of lightweight aggregate particles compared to conventional aggregates. However, high strength mixes, with final compressive strength of 8,000 psi, were produced using lightweight aggregates in partial replacement of 10% and 20% of conventional aggregates.

The measured strains of lightweight aggregate mixes were significantly lower than the control mix strains. Lower strains are attributed to the internal flow of water contained in the prewetted lightweight aggregates. The reduced shrinkage of concrete is extremely beneficial when structural members of large exposure is poured. In addition, the lightweight concrete results in a reduced structural deadload. The successful development of internally cured lightweight concrete could be utilized in pouring high strength bridge decks with improved performance against harsh environmental conditions, sulfate and chloride attacks, and de-icing salts.

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