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Experimental analysis of latex-solid content effect on early-age and autogenous shrinkage of very-early strength latex-modified concrete

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HIGHLIGHTS

- The overall trends of hydration temperature were similar regardless of latex-solid contents.
- Total and autogenous shrinkage increased with the increase in latex-solid content.
- The minimum six hours of wet curing is needed to minimize early-age shrinkage cracking.

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ABSTRACT

Very-early strength latex-modified concrete (VES-LMC) was developed for the purpose of creating a fast-track overlay of a concrete bridge deck, concentrating on the workability and strength gain so that the bridge can be opened to traffic within hours of placement. The mixture of VES-LMC might accompany very high heat of hydration at early-age because of its inherent rapid hardening property, and could be susceptible to autogenous shrinkage because of its relatively low water to cement ratio. From the field survey, some transverse and map cracking due to concrete material and construction issues were investigated in the bridge deck repaired with VES-LMC. This research focused on the effect due to material issue during early age.

This study evaluated the effect of the latex-solid contents of both the constant and variable slumps on the hydration heat and early-age shrinkages of VES-LMC by carrying out a simple heat of hydration test and early-age shrinkage experiment. The results are as follows:

The overall trends of hydration temperature were similar regardless of latex-solid contents within this study, although the initial setting by the latex-solid content varied a little. Total and autogenous shrinkage increased with the increase in latex-solid content. The total shrinkage occurs very quickly, with up to 80% of the maximum shrinkage during the first six hours after concrete placement, and the remaining 20% of shrinkage occurring during the next 18 h. It is, therefore, highly recommended to maintain the minimum six hours of wet curing of concrete in order to minimize early-age shrinkage and shrinkage cracking.

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1. Introduction

Very-early strength latex-modified concrete (VES-LMC) is currently used for the rapid restoration of existing concrete bridge decks. The biggest advantage of VES-LMC is that it develops a compressive strength over 21 MPa within three hours after its placement, thus shortening traffic closure time. Therefore, it has the advantage of minimizing the user's cost due to traffic impairment [1]. However, despite these advantages, rapid hydration at the early age can cause cracks, deteriorating its durability. The high temperature caused by hydration can induce thermal cracking, and the factors of early shrinkage including autogenous shrinkage can bring about shrinkage cracking. Thus, the possibility of early-age cracking can be greater for VES-LMC than for ordinary Portland cement concrete [2].

Although the definition of autogenous shrinkage differs by each researcher, it is agreed that it excludes loss of moisture and heat deformation while in the unconfined state. Lynam [3] defined autogenous shrinkage as the phenomenon of the volume change of concrete excepting various reasons such as the movement of moisture, temperature change, outside load, and confinement stress [4,5].

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Recently, the autogenous shrinkage committee of the Japan Concrete Institute (JCI) defined autogenous shrinkage as the volumetric reduction of the binder during the hydration of the cement after the initial hardening. Further, the committee specified that autogenous shrinkage does not include shrinkage due to the loss of material, penetration, temperature change, outside load, or confinement [6]. In the past, the influence of autogenous shrinkage was often overlooked because it was considered a significantly smaller deformation compared to drying shrinkage. However, research interest in autogenous shrinkage manifested during the process of making high performance and high strength concrete has recently increased.

VES-LMC is a high performance concrete developed for the purpose of rapid strength development, and the quantity of its binder is very large. Thus, it is expected that the influence of autogenous shrinkage on the early deformation can be significant. Yun et al. [7] evaluated the factors influencing thermal and autogenous shrinkages of VES-LMC in terms of latex-solid content, water to cement ratio, retarder content, and air detraining agent, and reported that the latex-solid content affects the autogenous shrinkage, while the other factors have little or no effect to the autogenous shrinkage. However, this study was limited to variable latex-solid contents only at a constant slump.

This study focused on the evaluation of latex-solid content on the heat of hydration heat and autogenous shrinkages of VES-LMC, with variable latex-solid contents both of the constant and variable slumps. The results of this study will help the field engineer and researcher to better understand the heat of hydration, autogenous, and early-age shrinkages of VES-LMC to reduce early-age cracking.

2. Cracking in VES-LMC overlay

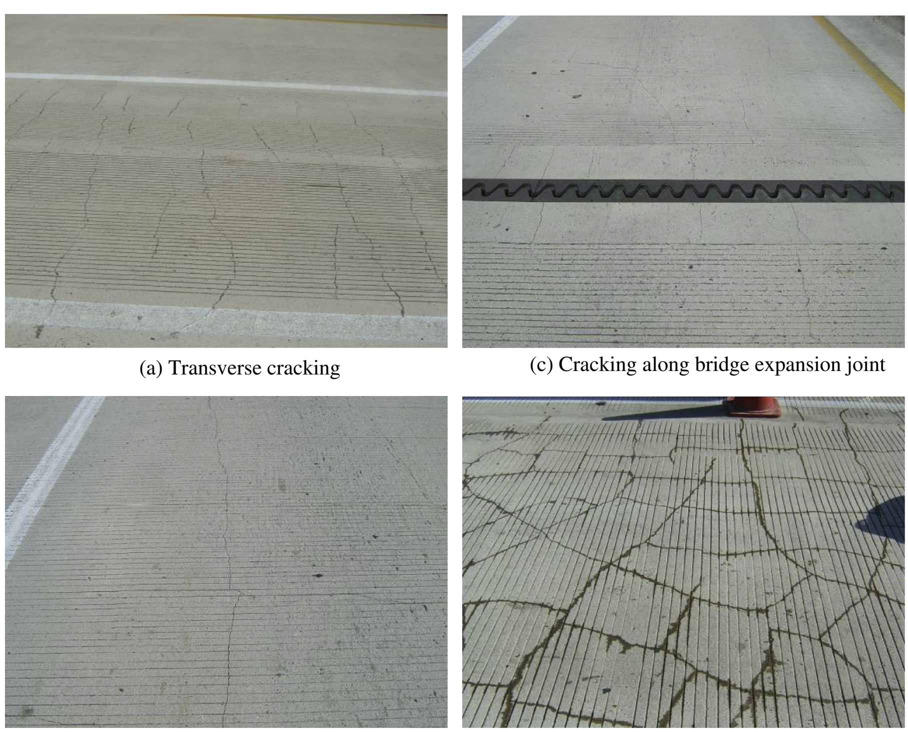
Fig. 1a is the typical transverse cracking due to large shrinkage development, heat of hydration and inadequate curing process in the early age [2,8]. Typically, transverse cracking due to concrete material and construction issues can be visible seven days after concrete placement. Fig. 1b shows the longitudinal cracking in the outside lane. Even though longitudinal cracking has been rarely observed, this is also one of the cracking patterns in VES-LMC overlay. Fig. 1c shows cracking near a bridge expansion joint, which could occur due to wheel load impact. This cracking is also not easily prevented in bridge expansion joint systems. Fig. 1d shows an example of map cracking due to debonding failure between overlaid concrete and existing substrate. Since map cracking usually occurs due to debonding failure related to seriously deteriorated substrate, it is not easy to prevent by improving the concrete material properties.

One of the best options to prevent the debonding failure is to apply the hydrodemolition process for removal of deteriorated and sound concrete. This process provides an excellent bonding surface for existing substrate and overlaid VES-LMC. Water jets are usually used for the hydrodemolition. Since high water pressure is applied to remove the deteriorated concrete, the hydrodemolition is a more efficient method than using jackhammers for removing deteriorated concrete [9]. Fig. 2a shows a picture of water jet equipment and application in bridge deck. Fig. 2b shows the condition of the bridge deck after the hydrodemolition. As can be seen in Fig. 2b, a solid concrete substrate and steels remain under high water pressure; however the deteriorated concrete is fully removed.

3. Experimental program

3.1. Concrete mixtures

The objective of this study was to evaluate the hydration heat, early-age and autogenous shrinkages in response to the change in latex-solid content, which affects the fundamental properties of VES-LMC. The evaluation of the property change in response to the change in latex-solid content can be approached in two different ways. The first is a method to evaluate the properties of VES-LMC by varying the latex-solid content only while all other conditions are kept constant. The



(a) Transverse cracking
(c) Cracking along bridge expansion joint
(b) Longitudinal cracking
(d) Map cracking due to debonding failure

Fig. 1. Cracking examples of VES-LMC in repaired bridge deck.

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