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Impact of Reducing the Latex Content in LMC Bridge Deck Overlays

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***Abstract*—Latex Modified Concrete (LMC) is ordinarily used as a thin overlay to shield bridge decks from the intensified application of deicers and environmental elements as well as the normal wear and tear due to traffic. LMC is an ideal concrete for bridge overlays due to its low permeability, inherent flexibility, and excellent adhesion. Another important quality for this concrete that can't be neglected is its lifespan. Currently, the standard is to use 24.5 gallons of latex for every cubic yard of concrete needed (121 L/m3). Recognizing that the latex is an expensive ingredient and its cost may dramatically increase when the oil prices are sky rocketing, the immediate objective of this research is to study the impact of reducing the quantity of latex used in a cubic yard of concrete. The goal is to reduce the initial cost of making the LMC by decreasing the amount of latex without affecting its performance and durability. The test results showed that LMC mix design with latex content of 20 gallons/yd3 (98.8 L/m3) has comparable performance to the typical LMC mix design with 24.5 gallons/yd3 (121 L/m3) in terms of compressive and flexural strengths, permeability, and shrinkage. This indicates that the latex cost could be reduced by about 20% without adverse effect on the major performance characteristics of the LMC overlays.**

Keywords—LMC, Latex, Overlay, Bridge Decks, Concrete Performance.

I. INTRODUCTION

Latex-modified concrete (LMC) is typically composed of coarse and fine aggregate, Portland cement, water, and latex emulsion. According to the Illinois Department of Transportation (IDOT) requirements [1, 2], the LMC overlay mix design shall contain the following approximate units of measure: 658 lb/yd3 (390 kg/m3) type I Portland cement, 24.5 gallon/yd3 (121.2 L/m3) latex admixture, coarse aggregate of 42 to 50% by weight of total aggregate, 157 lb/yd3 (93.2 kg/m3) maximum water, including free moisture on the fine and coarse aggregates, and no air entraining admixtures shall be added to the mixture. The LMC overlay mixture shall have a slump between 3 to 6 in. (75 to 150 mm) measured after 5 minutes from discharge, 7 percent maximum air content, and w/c between 0.30-0.40; considering all the non-solids in the latex admixture as part of the total water. For any bridge deck concrete overlay, the IDOT requires minimum of 4,000 psi (27,560 kPa) and 675 psi (4,650 kPa) compressive and flexural strengths at 14 days; respectively. LMC is dominantly used as bridge deck corrosion protection strategy with typical thickness of 2¼ in (57 mm) since it provides unique features include low permeability and inherent flexibility. Those two unique features are essential for prohibiting the infiltration of the chloride ions to the bridge deck reinforcement and provide excellent resistant to the freeze and thaw cycles, respectively. LMC overlays can also be open to traffic within 2-4 days and they adhere strongly to the underlying bridge deck. Therefore, LMC overlay are considered an optimum corrosion protection strategy for bridge decks.

LMC overlays were originally predicted to endure 20-30 years of abuse. Some LMC overlays constructed in 1974 are still in service today. However, many documented studies in literature reveal that LMC overlays are susceptible to cracking which in many cases occur at early age [3-11]. Reasons for such cracking were attributed to the use of inappropriate mix designs and/or inappropriate construction practices. However, Swanson [3] confirmed that cracking problems were noticed in spite of using adequate mix designs and construction practices. Consequently, the common cracking in LMC overlays might be attributed to the nature of the overlay as well as the aggressive loading and exposure condition. The LMC overlay thickness is just 2¼ in. (57 mm), the w/c ratio in a typical LMC overlay mix design is usually very low (around 0.37), and therefore, not enough bleeding water is available in the common dry environment and hot weather when the LMC overlays and other concrete overlay types are usually installed. The LMC overlay usually experience high drying shrinkage due to its high fine materials content and due to the short moist-curing period. The exposed surface area of the LMC overlay to drying is large. Movement and vibration of the bridge superstructure under the live loads and impact contribute to the cracking problem. In addition, the reflected cracks in the underlying bridge deck create critical stress condition at the bond interface between the overlay and the bridge deck. A potential solution for the frequent cracking is to use discontinuous fibers within the LMC mix design [11-13].

Currently, the standard is to use 24.5 gallons of latex for every cubic yard of concrete needed (121 L/m3). The latex cost is around $4/gallon, however during the high increase in the oil prices two years ago, the cost of the latex reached $10/gallon. Recognizing that the latex is an expensive ingredient and its cost may dramatically increase when the oil prices are sky rocketing, the immediate objective of this research is to study the impact of reducing the quantity of latex used in a cubic yard of concrete. The goal is to reduce the initial cost of making the LMC by decreasing the amount of latex without affecting its performance and durability.

II. Mix Designs and Test Specimens

In order to study the impact of the latex reduction, three LMC mix designs were prepared containing 24.5, 20, and 15 gallons of latex per cubic yard (121, 98.8, and 74 L/m3). As shown in Table 1, Mix 1 represents a typical LMC overlay mix design, while Mix 2 and Mix 3 were proportioned with approximately 20% and 40% lower latex content, respectively. It is important to notice that the coarse and fine aggregate contents in Mix 2 and Mix 3 were slightly greater than Mix 1 to compensate for the reduced latex from the unit volume. The three mix designs contained similar cement content, w/c ratio, and fine to coarse aggregate ratio. All the mix designs are based on saturated surface dry condition of the fine and coarse aggregates with specific gravities of 2.65. In the w/c calculation for the LMC, the latex is assumed to have 52% water and 48% solids based on the manufacturer data sheet.

TABLE I. LMC mix Designs per cubic yard

Ingredient	Mix 1	Mix 2	Mix 3
Type I Portland Cement	658 lb	658 lb	658 lb
Fine Aggregate	1390 lb	1420 lb	1440 lb
Coarse Aggregate	1390 lb	1420 lb	1440 lb
Styrene Butadiene Latex	24.5 gallon	20 gallon	15 gallon
Water	137 lb	157 lb	178 lb
w/c Ratio	0.37	0.37	0.37

* NOTE: 1 lb/yd3 = 0.593 kg/m3, 1 gallon/yd3 = 4.948 L/m3.

From each mixture, 6x12 in. (150x300 mm) cylinders, 4x8 in. (100x200 mm) cylinders, 6x6x21 in. (150x150x530 mm) beams, and 3½x3½x11 in. (90x90x275 mm) prisms; were used to test the performance of each mix design in terms of the compressive strength, flexural strength, permeability, and shrinkage of each mix design. Fig. 1 shows portion of the prepared test specimens. The compressive and flexural strengths tests were executed according to ASTM C39 and C78 at 4, 14, and 28 days from the date of casting. Both tests were conducted using a digitally controlled Tinius Olsen Universal Testing Machine (Figure 2). The permeability test was conducted for each mix design after 28 days using three specimens sliced from the 4x8 in. (100x200 mm) cylinders according to ASTM C1202. The shrinkage data were collected continuously over a 6 months period according to ASTM C157. All the specimens were moist-cured for 2 days followed by air curing in the lab environment.

Fig. 1 Specimens and Testing Machine

III. Fresh Concrete Properties

Similar mixing procedure was followed in the three mix designs to maintain consistency. The slump (measured after 5 minutes from discharge), air-content, unit weight, and temperature were measured for each mixture (Table 2). The slump values show significant reduction with the reduction in the latex content. Although Mix 2 had 20% reduction in the latex content, however its slump value was in the middle of the target range. Mix 3 was at the minimum allowable value since it has 40% lower latex content. The air content values and consequently the unit weight values were almost the same for the three mixtures. The air content values were lower than the maximum allowable 7% limit. The temperature values were also the same for the three mixtures since all the mixtures were made inside the same laboratory environment.

TABLE II. FRESH CONCRETE PROPERTIES

Property	Mix 1	Mix 2	Mix 3
Slump	6½ in. (165 mm)	4½ in. (165 mm)	3 in. (165 mm)
Air Content	4.5%	4.4%	4.7%
Unit Weight	143 pcf (2290 kg/m^3)	144 pcf (2305 kg/m^3)	144 pcf (2305 kg/m^3)
Temperature	77.6 °F (25.3 °C)	77.0 °F (25.1 °C)	76.6 °F (25 °C)

IV. FRESH CONCRETE PROPERTIES

Table 3 shows the compression and flexure test results for the three LMC mixtures at various ages. The average results were based on testing 2-3 specimens with coefficient of variation less than 3%. The 4-day compressive strengths for the three LMC mixtures were much greater than 5500 psi (38,000 kPa), which is much greater than the typical required 4000 psi (28,000 kPa) at 14 days. Mix 2 and Mix 3 both showed approximately 5% increase in the compressive strength at all ages compared with Mix 1. This could be attributed to that they have higher coarse aggregate content than Mix 1 replacing the 20% and 40% reduction in the latex. All of the three mixtures showed high compressive strengths at 14 and 28 days.

TABLE III. AVERAGE STRENGTH TEST RESULTS

Age (days)	Mix 1	Mix 2	Mix 3
Compressive Strength (psi)			
4	5550	5850	5820
14	7090	7340	7515
28	7670	7940	7900
Flexural Strength (psi)			
4	580	600	625
14	640	650	660
28	700	700	730

* NOTE: 1 psi = 6.89 kPa.

In terms of flexural strength, Mix 2 and Mix 3 showed slightly higher flexural strength than Mix 1 at 4 days, while approximately similar flexural strength at 14 and 28 days. For the three mixtures, the 14-day flexural strength was slightly lower than the typical required 675 psi (4660 kPa) flexural strength at 14 days. However, the 28-day compressive strength was higher than the required 14-day flexural strength. Based on the current standard latex content, with just a w/c ratio of 0.37, the initial slump value would be high, more than 8 in. (200 mm). This slump is achieved due to that the latex acts as a plasticizing agent in the fresh state. On the other hand, the low w/c ratio of the LMC results in high strength and high modulus. High strength LMC is not needed, compressive strength about 5000 psi (35,000 kPa) could be easily obtained with w/c around 0.4. Therefore, another benefit to the latex reduction could be the ability to increase the w/c ratio to 0.4 and thus reducing the strength and modulus of the LMC while maintaining its low permeability. This may help may help with the cracking problem of the LMC overlays.

V. DRYING SHRINKAGE

Figure 2 shows the shrinkage-time responses of the three LMC overlay mixtures measured according to ASTM C157. The difference in the shrinkage strains among the three mixtures was minimal at all ages. As shown in Figure 3, the three mixtures experienced high shrinkage strains. The rate of shrinkage was premier for the first 28 days followed by lower rate up to 90 days. The increase in the shrinkage readings was minimal after 90 days. The shrinkage readings exceeded 460 microstrain at 28 days and 700 microstrain at 90 days. This can be attributed to that the LMC overlay mixtures have high mortar content and wet-cured for 2 days only. These results may explain the high susceptibility of the LMC overlays to shrinkage cracking.

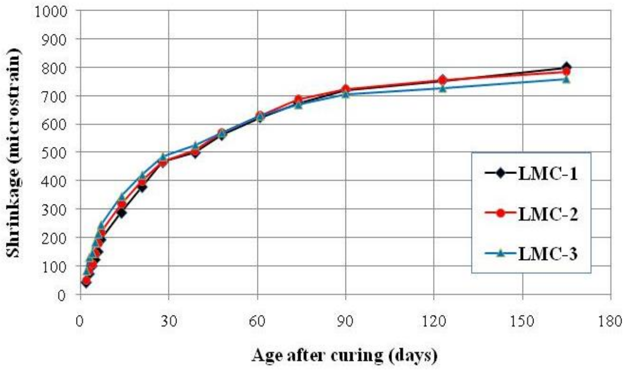

FIG. 2 SPECIMENS AND TESTING MACHINE

VI. PERMEABILITY

Rapid chloride permeability tests were conducted according to ASTM C1202, which entails the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. The obtained average coulomb values and the corresponding permeability classes as defined by ASTM C1202 are shown in Table 4. The results show a clear trend between the latex content the coulomb value; as the latex content decreases the coulomb value increases. Both the coulomb value and permeability class for Mix 1 were as expected for a typical LMC mix design with a latex content of 24.5 gallon/yd3 (121 L/m3) latex. The permeability class for Mix 2 is also very low, while the class is low for Mix 3 with an average coulomb value of 1766. Very low permeability class is favorable for any LMC mix design since its low permeability is the dominant reason for its use as bridge deck overlay.

TABLE IV. AVERAGE COULOMB VALUES AND PERMEABILITY CLASS

Specimen #	Mix 1	Mix 2	Mix 3
1	624	882	1857
2	566	959	1662
3	433	974	1780
Average	541	938	1766
Permeability Class	Very Low	Very Low	Low

VII. CONCLUSIONS

Reducing the latex content by 20% in a typical LMC overlay mix design does not adversely affect its major performance characteristics in terms of compressive and flexural strengths, shrinkage, and permeability. A 20% reduction in the latex content in LMC mixtures results in significant cost saving. A reduction of 40% of the latex content leads to a noticeable increase in the permeability of the LMC, despite the fact that the permeability class is still low.

VIII. ACKNOWLEDGEMENT

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