PERFORMANCE OF LATEX MODIFIED CONCRETE OVERLAY IN THE GULF ENVIRONMENT

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الخلاصـــة :

يعرض هذا البحث نتائج الدراسة على فعالية الطبقة الكاسية المصنوعة من الخرسانة اللثية (Latex Modified Concrete) تحت تأثير البيئة المحلية . لقد قُيِّمت مدى قدرة طبقه الخرسانة اللثية في تحسين متانة الخرسانة لمنع تآكل حديد التسليح . وتـمَّ تصنيع عدة بلاطات خرسانية ذات طبقات حامية مختلفة ووضعها في موقع معرض للتأثير الجوي . ثم مراقبة تآكل حديد التسليح لمدة عشرة أشهر وعمل رسم بياني لكمية الاملاح المتسربة على أعماق مختلفة من سماكة البلاطات الخرسانية في نهاية هذه الفترة . وقد تـمَّ التحقق من تأثير تغيرات الحرارة في منطقة الخليج العربي على نفاذية الخرسانة اللثية وذلك بواسطة تعريض مكعبات من الخرسانة اللثية لعدد ٦٠ ، ٩٠ ، ١٢٠ دورة حرارية ، ومن ثم قياس النفاذية عند كلٍّ من هذه الدورات الحرارية . كما تم التحقق من مدى تلاحم الطبقات الخرسانية وذلك باختبار كمرات مكونة من خرسانة لثية وخرسانة عادية تحت أحمال دورية ذات ضغوط مختلفة . وتشير النتائج إلى أنَّ فعالية طبقة الخرسانة اللثية في السيطرة على تسرب الرطوبة والاملاح أكثر من فعالية الخرسانة التي لاتحتوي على المواد اللثية . وكذلك لم يلاحظ أي انفصال بين طبقات الخرسانة تحت الأحمال الدورية ، وهذا مؤشرٌ إلى ضمان قوة التماسك بين طبقتي الخرسانة .

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ABSTRACT

This paper presents results of a study on the performance of latex modified concrete (LMC) overlay under the local environment. The assessment of LMC overlay to improve the durability of concrete against corrosion of rebars was evaluated. Several panels with two different overlay thicknesses were cast and subjected to natural local environments in an exposure site. Corrosion of rebars was monitored for a period of ten month and chloride *versus* depth profile of the slabs were plotted at the end of the monitoring period. The effect of the large temperature variations in the Arabian Gulf on the permeability of LMC overlay was investigated by subjecting test cube specimens to 60, 90, and 120 heat cycles and measuring the corresponding permeability. Finally, the delamination phenomenon was investigated by testing composite beams consisting of LMC overlay and base concrete under cyclic loading at different stress levels.

The test results indicate that the LMC overlay is more effective than super plasticized portland cement concrete (SPCC) in controlling the permeation of moisture and chloride. The half-cell potential readings reflected a substantial delay of corrosion initiation by using 40 mm thick LMC overlay relative to a 25 mm thick LMC overlay and to a control panel with no overlay. Also it indicates the beneficial effects of latex in resisting the thermal incompatibility of concrete components measured in terms of permeability. Good bond between LMC overlay and base concrete is ensured as no delamination was observed under cyclic loading with peak load ot up to 80 percent of the ultimate load.

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INTRODUCTION

In the Arabian Gulf region, the concrete deterioration problem has been reported [1] where numerous concrete structures of all sizes and shapes appear to deteriorate at an extraordinarily accelerated rate. The adverse climatic conditions of high temperature and humidity and severe ambient and ground salinity coupled with scarcity of good quality raw materials have created an environment conducive to initiating corrosion of reinforcement, which has been identified as the number one concrete deterioration problem in the Arabian Gulf area [2, 3]. In the Eastern Province region of Saudi Arabia, premature and accelerated corrosion of bridge decks has been reported [4] where deck chloride profiles have indicated severe gradients of chloride ions, concomitant with chloride content as high as $18\,kg\,m^{-3}$.

Deterioration of ordinary portland cement concrete (PCC) bridge decks in Eastern region of Saudi Arabia has drawn attention towards the development of latex modified concrete (LMC) as an overlay for bridge decks. In a recent study, LMC has been developed using local available materials from the Eastern Province of Saudi Arabia to achieve a stronger and less permeable concrete [5].

The first LMC bridge deck overlay was placed in West Virginia in 1961. Performance of this overlay was considered very good over the years. Subsequently, many bridge decks have received LMC overlays since 1970, both in new construction and during rehabilitation of deteriorated bridge decks. Kuhlmann [6] studied performance history of LMC overlay for 184 bridge decks, aged two months to thirteen years. Performance was measured in terms of chloride penetration and half-cell potential. Life expectancy, based on testing as well as the actual life in the field, was projected to be a minimum of 15 to 20 years. Bishara [7] evaluated the performance of LMC overlay for 132 bridge decks and concluded its effectiveness as a protective system. As no work to date has been reported in the Kingdom of Saudi Arabia on the performance of LMC overlay, this research has therefore been carried out in order to evaluate the performance of LMC overlay subject to the harsh environmental conditions prevalent locally and using locally available materials.

Laboratory investigation on the performance of LMC overlay was carried out at King Fahd University of Petroleum & Minerals. Several panels with different thickness of LMC overlay were cast and placed at an exposure site where corrosion of rebars was monitored over a period of ten months. Chloride *versus* depth profiles of the slabs were also plotted to determine the effectiveness of overlay in preventing the permeation of chloride and moisture. The effect of the large temperature variation in the Arabian Gulf on permeability was investigated separately by subjecting test cube specimens to different number of heat cycles and measuring the corresponding permeability according to DIN standards. Several composite beams consisting of LMC overlay and base concrete were tested under cyclic loading at different maximum stress levels to investigate the composite action and possibility of delamination. Beams with overlay at the top and at the bottom were tested so as to simulate behavior of the composite section in both the positive and the negative moment regions.

EXPERIMENTAL PROGRAM

Materials

Materials used were Portland cement ASTM Type I, beach sand, Dhahran aggregates, superplasticizer (CONPLAST 430), and nitrobond styrene–butadiene rubber latex (the basic properties are listed in Table 1) were used. Chemical composition of Portland cement ASTM Type I is listed in Table 2. Mineralogical composition of sand and of coarse aggregate is listed in Tables 3 and 4, respectively [8]. Physical properties of sand are given in Table 5 and Table 6 lists the physical properties of coarse aggregates [8]. The sand and coarse aggregate gradations are shown in Table 7 and Table 8, respectively.

Mix Proportion

An optimum mix design of LMC was prepared in accordance with that used by Sharif *et al.* [5] in order to achieve a stronger and less permeable concrete. The following proportions were used: water to cement ratio (W/C) of 0.40, polymer to cement ratio (P/C) of 0.10, sand to aggregate ratio of 0.5, and cement content of $416\,kg\,m^{-3}$. The mix design of the base concrete and the control specimens was prepared using superplasticizer to reduce the water–cement ratio and subsequently reduce non-structural

Table 1. Properties of NitroBond SBR

Total Solids (%)	Specific Gravity at 20°C	pH at 20°C	Viscosity at 20°C cP
45.0	1.02	10	40.0

Table 2. Chemical Composition of Type-I Cement

CaO	63.6	Na_2O	0.12
SiO_2	20.7	K_2O	0.94
Al_2O_3	5.96	I.R.	0.26
Fe_2O_3	2.35	Ig Loss	1.37
MgO	2.58	Free CaO	1.43
SO_3	2.13		

Table 3. Mineralogical Composition of Sand

Sample #	Mineralogical Composition			
UPS-3	Calcite	Quartz	Gypsum	Feldspar

Table 4. Mineralogical Composition of Coarse Aggregate

Sample #	Mineralogical Composition		
UA-14	Calcite	Quartz	dolomite

Table 5. Physical Properties of Sand

Specific Gravity	2.77
Absorption (%)	0.277
Fineness Modulus	1.44
Angularity Factor	1.000

Table 6. Physical Properties of Coarse Aggregate

Bulk Specific Gravity	2.25
Apparent Specific Gravity	2.54
Absorption %	4.97
Apparent Porosity %	11.20
Soundness % Loss	6.18
Abrasion % Wear	33.97
Unit Weight ($kg\,m^{-2}$)	1334.3
Compression Strength (MPa)	40.0

Table 7. Sand Gradation

Sieve Size (μ mm)	% Retained	% Passing
600	3.35	96.65
300	48.40	48.25
150	37.20	11.05
75	10.82	0.23

Table 8. Coarse Aggregate Gradation

Sieve Size (mm)	% Retained	% Passing
12.5	20	80
9.5	40	40
4.75	4	0

cracks as recommended by a study on bridge deck cracking in Saudi Arabia [4]. The following proportions were used: W/C = 0.50, superplasticizer to cement ratio of 0.011, sand to aggregate ratio of 0.67, and cement content of $350\,kg\,m^{-3}$.

Specimen Preparation and Testing

Assessment of LMC Overlay

To evaluate the effectiveness of LMC overlay against rebar corrosion, a total of three panels ($1500\,mm \times 750\,mm \times 150\,mm$) were cast with different overlay thicknesses above the reinforcement to study their relative corrosion potentials. Table 9 gives the panel number, overlay thickness, the date of casting and the date of first half-cell potential measurement.

Panels 2 and 3 were constructed in two stages; superplasticized portland cement concrete (SPCC) was cast first (Figure 1) and cured for five days, after which the LMC overlay was cast on top of the SPCC base concrete and wet cured for two days. The panels were then demolded and left to dry cure at ambient temperature for an additional two weeks. The top surface of the SPCC was wetted prior to the placement of the LMC overlay. All panels were subjected to accelerated corrosion by ponding them with: (*a*) 3% salt solution for the first week as shown in Figure 2; (*b*) tap water for the second week; and (*c*) 1% salt solution for the subsequent six weeks. Alternate wetting and drying of panels was continued to the end of the test. The salt concentration is reduced from solutions (*a*) to (*c*) so that the corrosion initiation could be detected by the half-cell potential readings.

Table 9. Details of Corrosion Monitoring Panels

Panel Number	LMC Overlay Thickness (mm)	Date of Casting	Date of First Half Cell Potential Measurement
1	00.0	1 October 1987	30 November 1987
2	25.0	1 October 1987	30 November 1987
3	40.0	15 July 1987	15 September 1987

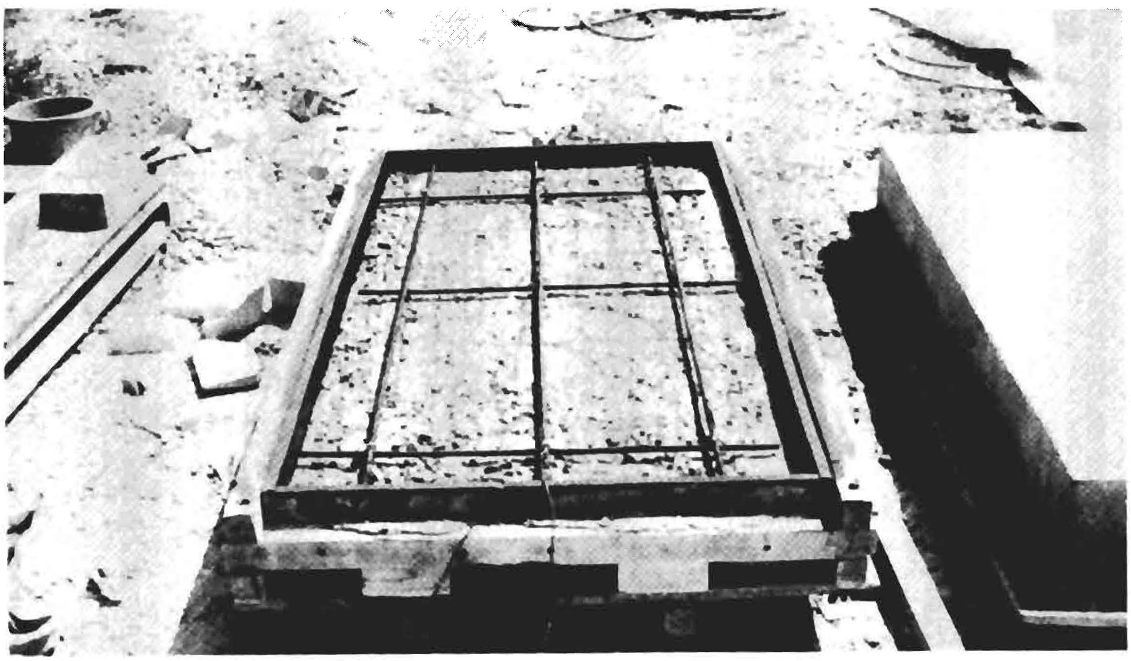

Figure 1. First Stage Construction of Panel with LMC Overlay.

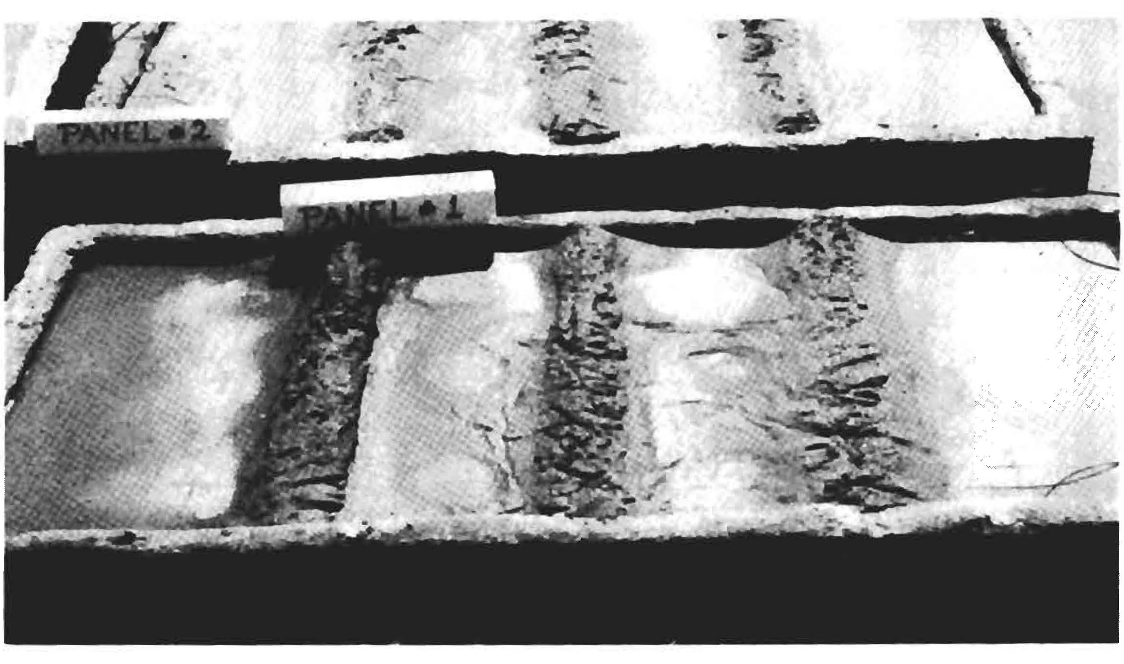

Figure 2. Panels Ponded with 3% Salt Solution.

The state of corrosion in these panels was recorded by using copper–copper sulfate half-cell potential measurements according to ASTM C 876-77. Figure 3 shows the detailed reinforcement and the attached leading wires for half-cell potential measurements. The location of points on these panels for half-cell potential measurements are also shown in Figure 3.

The chloride profile in panels 1 and 2 was determined at the end of the test by extracting (50 mm × 150 mm) cores which were analyzed for chloride content at different levels throughout the depth as shown in Figure 4. The chloride profile for panel 3 was not determined since the panel was subjected to further accelerated corrosion.

Effect of Heat–Cool Cycles on LMC

To investigate the effect of heat cycling on permeability of both LMC and SPCC specimens, a total of twelve 200 mm cubes were prepared for each concrete. One heat–cool cycle consisted of heating the specimens up to 80°C for about 6 hours, followed by a cooling period of another 6 hours, thereby completing two heat–cool cycles per day. Three specimens each were subjected to 60, 90, and 120 heat–cool cycles, whereas three specimens were kept as control specimens under laboratory conditions for both LMC and SPCC mixes. After the completion of thermal cycling, all the specimens were tested for water permeability according to DIN specifications 1048. In this test, water pressure of 1 bar is applied for 48 hours followed by water pressure of 3 bars and 7 bars for 24 hours each. At the end of the fourth day, the specimen is split into two halves and maximum depth of water front is measured for each sample.

Composite Beams Subjected to Cyclic Loading

A total of twelve beam specimens (990 mm × 300 mm × 150 mm) were cast. The beam dimensions and detailed reinforcement are shown in Figure 5. All beams were cast in two stages, with the construction

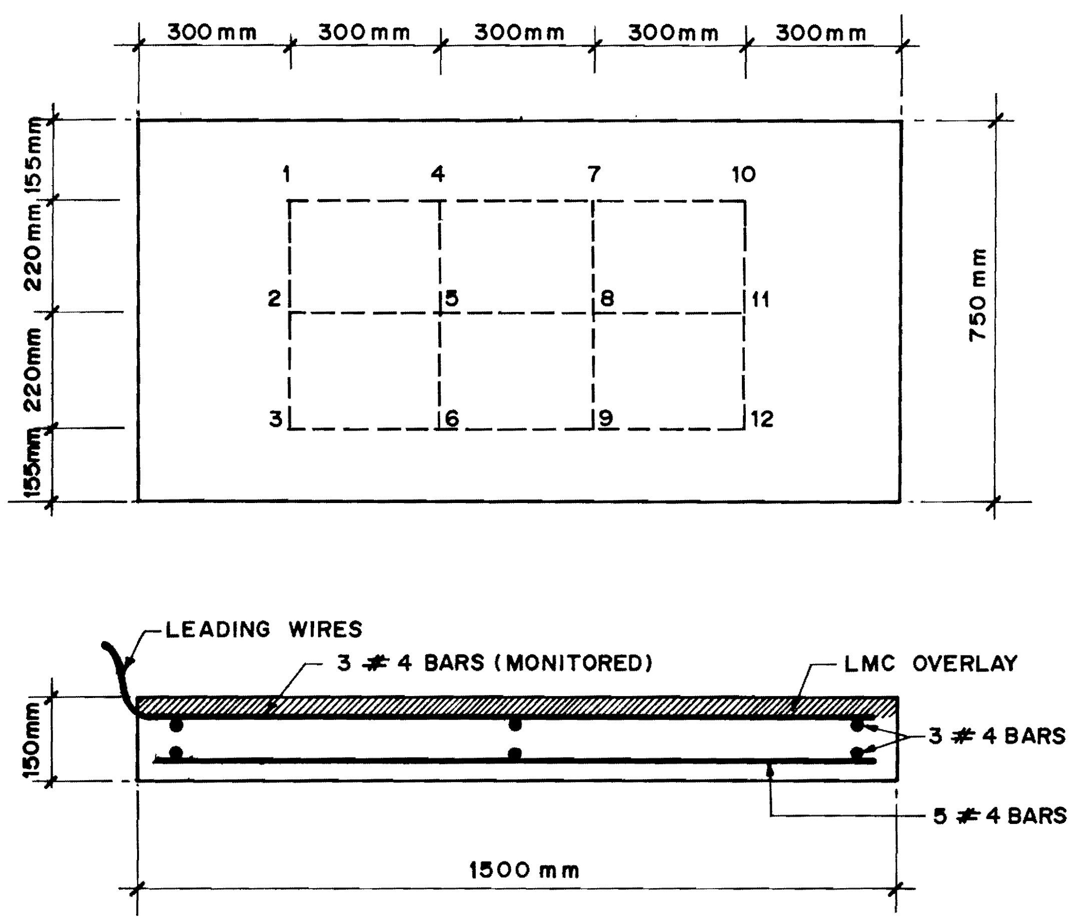

Figure 3. Reinforcement Detail and Points for Half-Cell Potential Measurements Corrosion Panel.

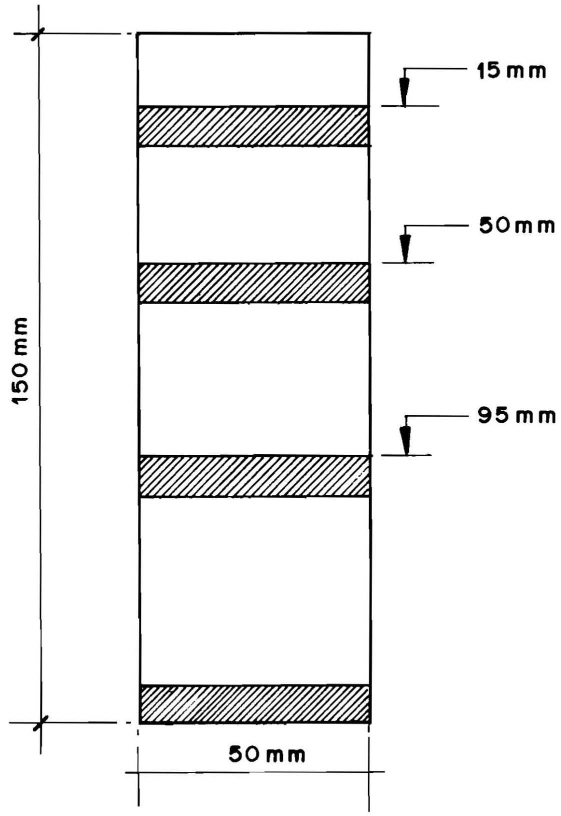

Figure 4. Core Sample Showing Slices 15 mm Thick Analyzed for Chloride Content.

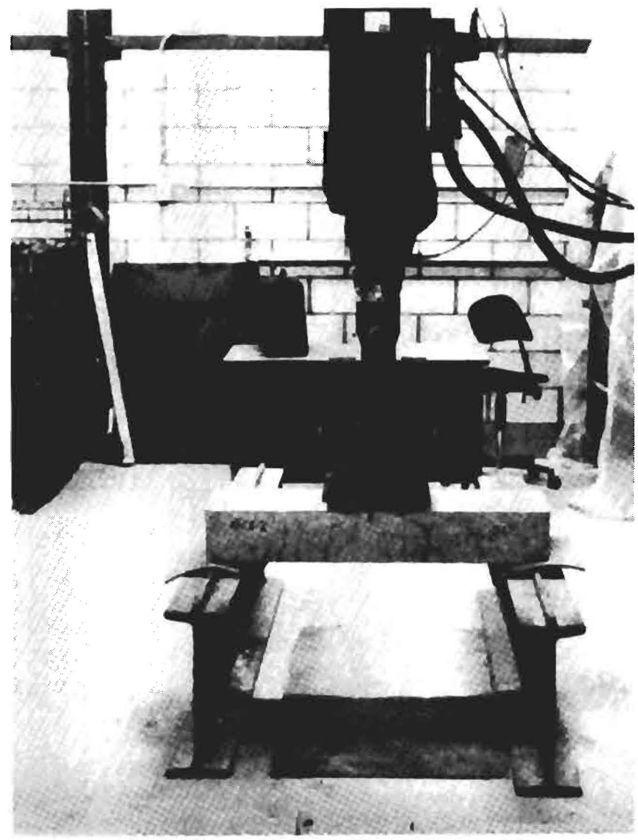

Figure 6. Test Setup for Composite Beam.

methodology being exactly similar to the panels adopted for corrosion studies as discussed earlier. The ultimate capacity of the beams was estimated by loading in a static mode to failure. Four beams were tested under static loading, two for each LMC overlay in compression and in tension. Eight beams were tested under cyclic loading, four for each LMC overlay in compression and in tension. The cyclic loading was applied between the minimum and maximum load at a rate of 2 Hz up to 200 000 cycles or failure of the beam, whichever occurred first.

A stress range of $R = \sigma_{min}/\sigma_{max}$ of 0.10 was used, corresponding to a minimum stress level of 10 percent of the maximum applied stress. The minimum stress level used simulated the dead load of a structure, prevented stress reversals and held the specimen in place. Two maximum stress levels, 60 percent and 80 percent of the ultimate static load, were applied on two beams each. All beams were tested as simply supported under two point loads as shown in Figure 6. Observations of delamination or failure during cycling were also recorded.

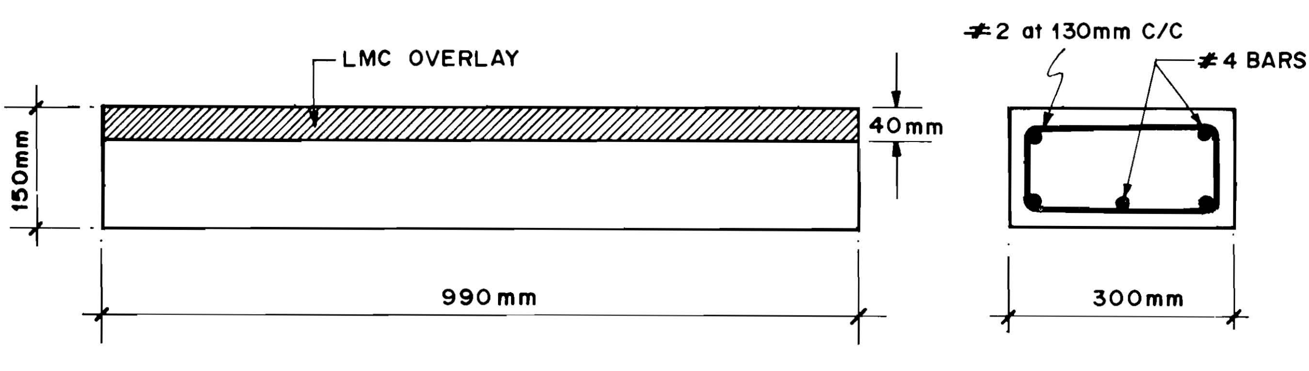

Figure 5. Dimensions and Reinforcement Details of Composite Beam Specimen.

RESULTS AND DISCUSSION

Assessment of LMC Overlay

The electrical half-cell potential of reinforcing steel was monitored with time at 12 predetermined positions on the surface of each slab. The frequency of half-cell potential monitoring was twice per week for the first four weeks and once a week thereafter. The values of half-cell potential of reinforcement measured with respect to the saturated copper–copper sulfate electrode and generally accepted as representing corroding and non-corroding conditions are: (*i*) potentials consistently more negative than −0.35 volts: high probability of corrosion; (*ii*) less negative than −0.20 volts: high probability of no corrosion; and (*iii*) in the range of −0.20 to −0.35 volts: uncertain as regards to the condition of reinforcing steel which may be active or passive. Half-cell potential readings for the slabs made up of SPCC alone and with 25 mm and 40 mm thickness LMC overlay are shown in Figure 7. The results clearly indicate the better performance for the slabs with LMC overlay in comparison to the slab without an overlay under such an environment. The results also indicate that corrosion initiation (*i.e.* half-cell potential readings reaching −0.35 V) starts within about one week in concrete slab without LMC overlay, about two weeks in concrete slab with 25 mm LMC overlay, and about 16 weeks in concrete slab with 40 mm LMC overlay. Such considerable improvement of the 40 mm LMC overlay over the 25 mm LMC overlay is due to the increase in the top rebars cover by 15 mm.

Chloride–depth profiles for the slabs without overlay and with 25 mm thick overlay are shown in Figure 8. Effectiveness of the overlay in preventing the permeation of chlorides from the top surface of the slab in comparison to the slab without any overlay is clearly manifested. At the level of top reinforcement, the chloride content in the slab with 25 mm overlay is about 0.084 percent by weight of concrete and that of slab without overlay is about 0.155 percent by weight of concrete indicating an increase of 46% of chloride content.

Effect of Heat Cycles on LMC

High temperature variations accompanied with large differences in coefficient of thermal expansion of concrete constituents causes high internal stresses built up which lead to crack formation within the matrix [10]. The problem of thermal incompatibility of concrete components (TICC) using limestone aggregates [11] has shown to lead to an increase in

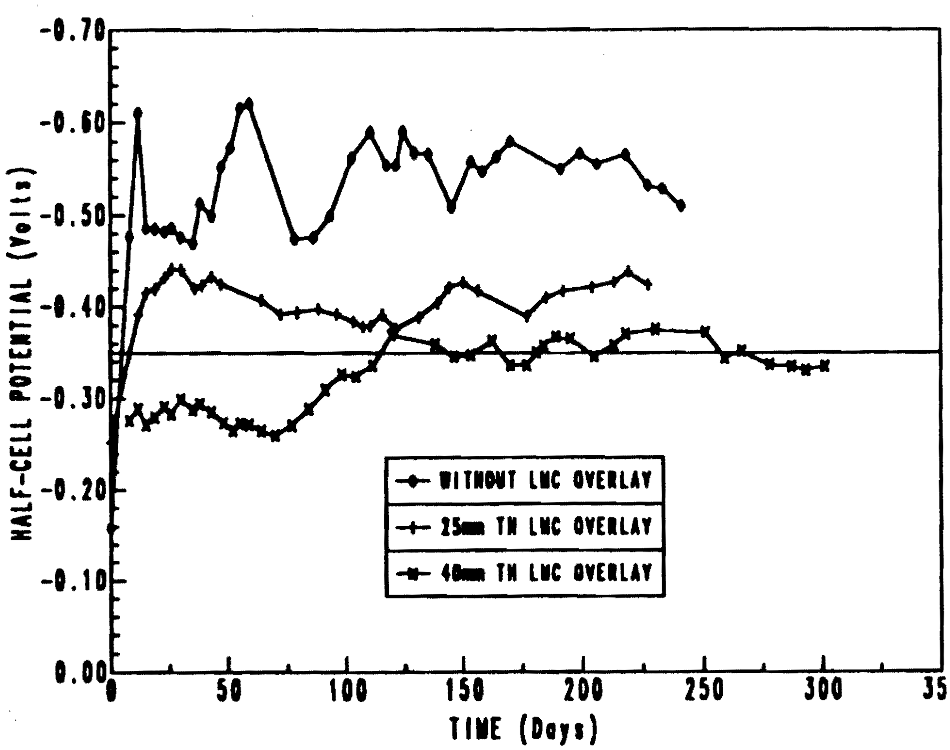

Figure 7. Half-Cell Potential Readings versus *Time.*

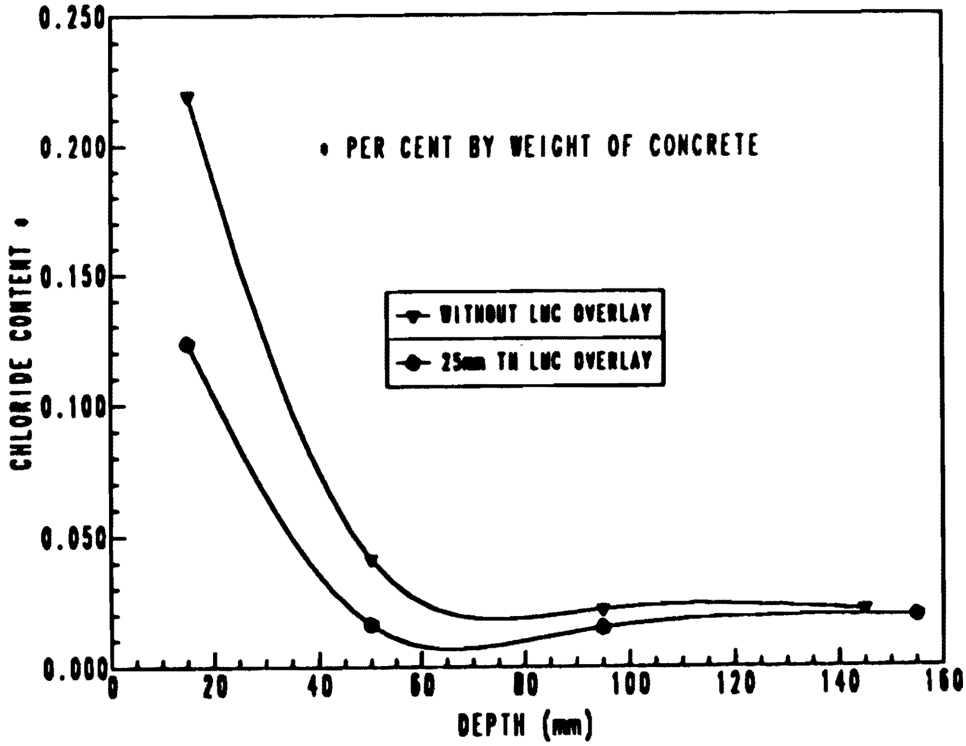

Figure 8. Chloride Content Variation versus *Depth.*

permeability due to the degradation of concrete as a result of this phenomenon.

Results of permeability testing on thermally cycled specimens are shown in Figure 9 for LMC, SPCC, and PCC, in terms of water penetration depth *versus* number of heat–cool cycles. Data on permeability of PCC is obtained from Reference [12], where the same materials were used with the following mix proportions: W/C = 0.71; sand-to-aggregate ratio of 0.67; and cement content 350 kg m^{-3}. LMC specimens show the best resistance to TICC in terms of permeability as compared to SPCC and PCC specimens. The increase in water depth penetration from zero to 120 heat cycles for LMC, SPCC, and PCC specimens is 22 mm, 46 mm, and 58 mm, respectively. This indicates a faster rate of concrete deterioration due to TICC for SPCC and PCC specimens relative to LMC specimens and is depicted in Figure 9.

Composite Beams Subjected to Cyclic Loading

The ultimate static load for beams with overlay in compression or in tension was similar and approximately 55 kN. Under cyclic loading with maximum stress level of 60 percent of the ultimate static load, only vertical flexural cracks appeared at midspan and under the two point loads. Neither failure nor development of cracks were observed in beams with overlay in compression or in tension up to the 200 000 cycles at which the test was discontinued. Under the cyclic loading with maximum stress level of 80 percent of the ultimate static load, a similar crack pattern was observed as described above, except that cracks propagated to a greater depth. Two cracks at the extreme ends of the beam began to propagate diagonally as the number of cycles increased. Failure then occurred with the formation of an arch type crack between the support and the point load as shown in Figure 10. The performance of beams with overlay in compression or in tension was nearly the same and failure occurred at around 650 cycles. However, there was no evidence of failure of the bond between the overlay and the base concrete even at such high stress level. This behavior testified to the good bond existing between the base concrete and LMC overlay, which had been obtained simply by wetting the base concrete surface before casting the LMC overlay.

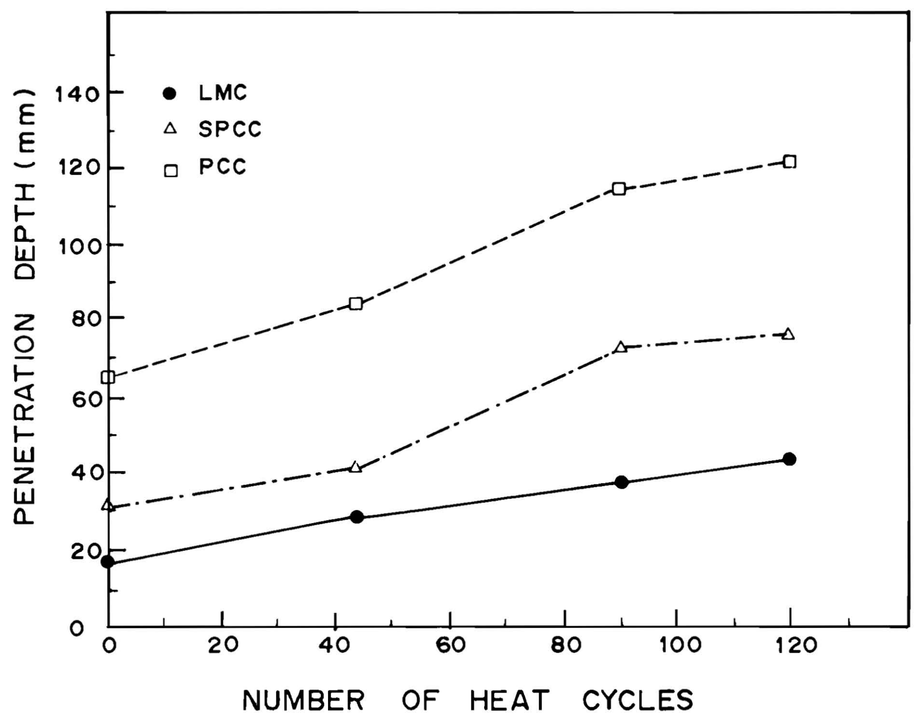

Figure 9. Depth of Water Penetration versus *Heat Cycles.*

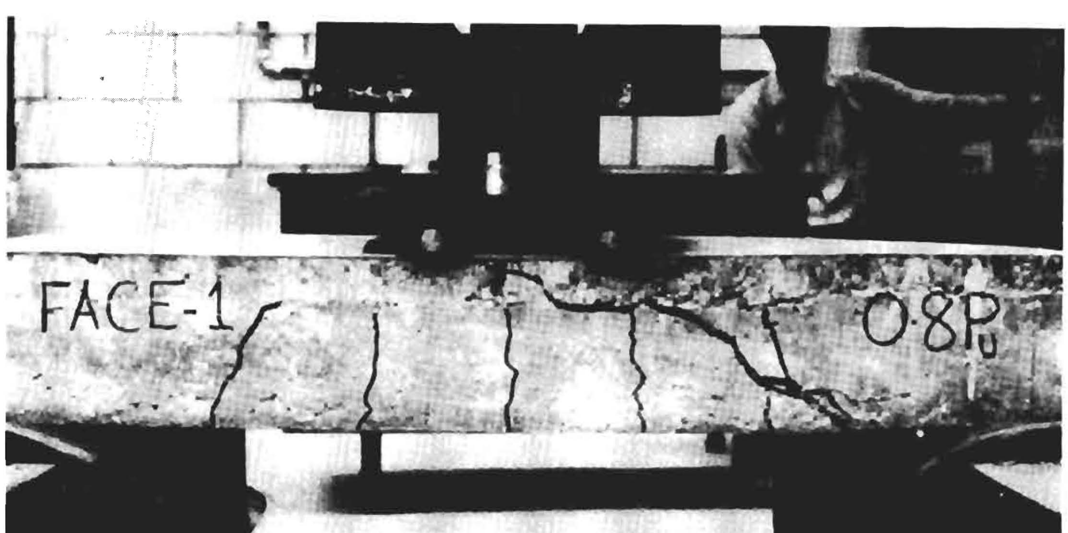

Figure 10. Failure of Composite Beam Under Cyclic Loading When Subjected to 80 Percent of Ultimate Static Load.

CONCLUSIONS

1. LMC overlay is effective in controlling the permeation of moisture and chloride relative to superplasticized portland cement concrete (SPCC).
2. Slabs with 40 mm thick overlay show considerably improved relative time of corrosion initiation as compared to slabs without and with 25 mm thick LMC overlay.
3. Chloride content at the level of top reinforcement is reduced by 46% by using 25 mm thick LMC overlay, relative to an equal thickness of SPCC.
4. LMC specimens subjected to thermal cycling indicated a lower rate of concrete deterioration due to TICC as compared to SPCC and PCC.
5. In the absence of any observed delamination in both static and cyclic tests, it can be concluded that adequate bond between the overlay and base concrete can be achieved by following specified construction methodology.

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