DEVELOPMENT OF LATEX MODIFIED CONCRETE IN SAUDI ARABIA: MATERIAL ASPECT

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الخلاصة :

يهتم هذا البحث بتطوير الخرسانة اللثيه (Latex Modified concrete) باستعمال المواد المحلية . وقد استعمل البحص الجيري (جبل الظهران) في تصميم الخلطة الخرسانية المثالية لتقييم فعالية المواد اللثيه (Latex) في تطوير النوعية المنخفضة لهذه الخرسانة . واشتملتْ دراسة المتغيرات على كلٍّ من : نسبة المواد اللثيه للاسمنت ، ونسبة الماء للاسمنت ، ونسبة الرمل للبحص ، وكمية الاسمنت . وتمَّ اختيار الخلطة الخرسانية المثالية لاستعمالها كطبقة حامية أو عازلة ، بحيث تكون قليلة النفاذ وسهلة الخلط وجيدة القوة . ويجب عند استعمال الخرسانة اللثيه تشييدها على مرحلتين وعندئذ يجب التأكد من تماسك طبقات الخرسانة كما ويتمّ اختيار المعالجة السطحية على أساس قوتها القاصة وجوانبها الاقتصادية .

وقد أثبتت نتائج الاختبارات المعملية الآتي : (١) أن سهولة الخلطة تزداد بازدياد نسبة المواد اللثيه للاسمنت ، (٢) وأن الدرجة المثالية لنسبة المواد اللثيه للاسمنت هي (٠,١٠) ، وقد أعطت أحسن نتائج لقوة الضغط وقوة الشَّد الشطري وقوة الإلتواء ، (٣) وأن أقل نفاذ للخرسانة قد تَمَّ الحصول عليه عندما كانت نسبة المواد اللثيه للاسمنت (٠,١٥) ، (٤) وأن أشد قوة تماسك بين طبقتي الخرسانة اللثيه والخرسانة العادية المتحجرة قد تَمَّ الحصول عليها عند تبليل الطبقة السطحية للخرسانة العادية .

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ABSTRACT

This paper is concerned with the development of latex modified concrete using local materials. The mix design was prepared using marginal aggregates (Jebel Dhahran) to evaluate the effectiveness of latex in upgrading concrete made of low quality aggregate. The variables studied includes polymer–cement ratio, water–cement ratio, sand–aggregate ratio, and cement content. The appropriate mix design is chosen based on the application of latex modified concrete as a protective system to attain low permeability, reasonable slump, and good strength. The use of latex modified concrete in two-stage construction requires good bond so the best surface treatment is chosen, based on Arizona slant shear test and economy.

The test results have shown that (*i*) workability increases as polymer–cement ratio increases, (*ii*) an optimum value of polymer–cement ratio of 0.10 gives the best results in compression, splitting-tensile and flexural strengths, (*iii*) the least permeable concrete is obtained at polymer–cement ratio of 0.15, and (*iv*) wet surface treatment given to normal concrete surface yields the best results for bonding latex modified concrete to hardened Portland cement concrete.

DEVELOPMENT OF LATEX MODIFIED CONCRETE IN SAUDI ARABIA: MATERIAL ASPECT

INTRODUCTION

Recent inspection of three bridge decks [EP1, EP2, & EP3] on the Abu-Hadriyah–Dammam road showed severe cracking in the asphalt road surface [1]. Subsequent chiselling of the concrete in the delaminated zones showed definite signs of reinforcement corrosion, and in some places the reinforcement had disintegrated entirely. Calomel half cell potential measurements were made, and all the readings indicated a state of active corrosion. In addition, cores 5 cm in diameter and 20 cm in depth were taken from each of the bridges for chloride profile determination. Chloride profiles over the top 20 cm for two of the bridges identified as EP1 and EP2, showed an extremely high gradient of Cl^- level with maximum of 18.8 kg m^{-3} for EP1 and 5.42 kg m^{-3} for EP2. The third bridge EP3 had a maximum Cl^- level of 1.98 kg m^{-3}. The threshold level of Cl^- to activate corrosion varies from 0.67 kg m^{-3} to 0.98 kg m^{-3} for normal range of cement content from 335 kg m^{-3} to 490 kg m^{-3}. Thus the Cl^- level far exceeds the threshold level throughout the top 20 cm region in all the three bridges inspected, which indicates that the top reinforcement is susceptible to corrosion. It has been noted that there is a definite indication of chloride ingress from the top surface. If the chloride contamination were only to be from aggregate contamination and/or mix water, the gradient would not have been as pronounced.

Deterioration and subsequent failure of ordinary Portland cement concrete bridge decks in the Kingdom of Saudi Arabia have drawn the attention of researchers towards the development of dense, high strength, and less permeable concrete. Therefore, by using latex modified concrete (LMC) overlay on the top surface of the bridge decks, it is desired to achieve a stronger and less permeable concrete. This would prevent the penetration of chloride ions, moisture, and oxygen to the underlying reinforcement, thereby inhibiting the corrosion process.

Concrete made with Portland cement is a popular construction material throughout the world. However, Portland cement concrete (PCC) has some disadvantages such as low tensile strength, delayed hardening, susceptibility to severe moisture and temperature changes, and tendency to deteriorate as a result of its absorption capacity. Improvements in these properties could significantly extend the usefulness of concrete components. In an effort to achieve these improvements many investigations using polymers in cement concrete have been actively conducted in various countries, particularly Japan, U.S.A., U.S.S.R., West Germany, and U.K. for the past 30 years or so [2–7]. Ohama [2–4] has done most of the work on understanding the principles of latex modification of cement mortar and concrete. He has also proposed a systematic approach towards mix design of LMC advancing the concepts of slump control factor and binder void ratio. He has discussed in detail the use of materials and methodology adopted in the preparation of latex modified concrete. His work includes the study of latex modified concrete properties in both the fresh and hardened states and the actual application of latex modified concrete. Akihama, Morita, Watanabe, and Chida [5] have discussed the effect of polymer–cement ratio (P/C) and water–cement ratio (W/C) on compressive strength and static modulus of elasticity of latex modified concrete. They concluded that there is an optimum polymer–cement ratio of about 0.15% by weight which gives the best results. Popovics [6] has performed extensive research on the study of latex modified concrete properties and concludes that beneficial effects are seen mainly on the flexural, tensile, and bond strength of latex modified concrete. He has also concluded that the maximum concrete strength increase is obtained with 0.15 to 0.20 polymer–cement ratio. Nawy, Ukadike, and Sauer [7] have investigated the effect of polymer–cement ratio and water–cement ratio on slump, splitting-tensile strength and compressive strength. Their results showed an optimum value of polymer–cement ratio at a particular water–cement ratio. Since no work to date has been reported in the Kingdom of Saudi Arabia on the use of latex as a concrete admixture, this research has been carried out in order to come up with the optimum mix proportions for the latex modified concrete using locally available materials.

In this regard, laboratory investigation on the use of latex in ordinary concrete was carried out at King Fahd University of Petroleum & Minerals. A number of properties of both the fresh and hardened concrete were determined. Tests on fresh concrete included the determination of slump and air content whereas compressive strength, split-tensile strength, flexural strength, permeability, and shear bond strength tests were carried out on hardened concrete.

EXPERIMENTAL PROGRAM

Materials

Materials used for this experimental work were locally available. Portland cement Type I, beach sand, Dhahran aggregate, and Nitobond styrene–butadiene rubber latex manufactured by Fosroc Fosam in Saudi Arabia (the basic properties are listed in Table 1) were used. Chemical composition of Portland cement Type I is shown in Table 2. Mineralogical composition of sand and coarse aggregate are given 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 aggregate [9]. The coarse aggregate used are very weak in strength, quite friable, chalky and have poor soundness and abrasion properties. Most of the aggregates in the Eastern Province are salt contaminated [9, 10] and contain chert and silica which is most likely to generate alkali–silica reaction in concrete [11]. The sand and coarse aggregate gradations are shown in Table 7 and Table 8, respectively.

Table 1. Properties of NitoBond 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	Absorption (%)	Fineness Modulus	Angularity Factor
2.77	0.277	1.44	1.000

Table 6. Physical Properties of Coarse Aggregate

Bulk Specific Gravity	2.25
Apparent Specific Gravity	2.54
Water Absorption (%)	4.97
Apparent Porosity (%)	11.20
Soundness (%) Loss	6.18
Abrasion (%) Wear	33.97
Unit Weight (kg m^{-3})	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	40	0

Mix Proportions

The following mix proportions and variables were used as a part of ten trial mixes, each of volume 0.05 m^3.

1. Polymer–cement ratios (P/C) of 0.05, 0.10, 0.15, and 0.20 were used, being determined as weight of polymer solids to weight of cement, while a water–cement ratio of 0.40, a sand–aggregate

ratio of 0.50, and a cement content of 416 kg m^{-3} were kept constant.

2. Water–cement ratios (W/C) of 0.40, 0.45, and 0.50 were used keeping a polymer–cement ratio of 0.10, a sand–aggregate ratio of 0.50, and a cement content of 416 kg m^{-3} as constant.
3. Sand–aggregate ratios (S/A) of 0.40, 0.50, and 0.60 were investigated keeping a polymer–cement ratio of 0.10, a water–cement ratio of 0.40, and a cement content of 416 kg m^{-3} as constant.
4. Cement content values of 356, 416, and 475 kg m^{-3} were used keeping a polymer–cement ratio of 0.10, a water–cement ratio of 0.40, and a sand–aggregate ratio of 0.50 as constant.

Mixing Procedure and Curing

A mixture of cement, sand, and aggregate was mixed dry for 90 seconds in a drum-type mixer. Latex was premixed with the water and added slowly to the dry mix for an additional two minutes of mixing.

Latex modified concrete contains two types of binders, namely cement and latex. For cement hydration and subsequent development of strength of the cement phase, wet cure is recommended, but for the development of the polymer film phase, dry cure is suggested. Therefore, in order to achieve optimum properties for latex modified concrete a combination of wet and dry cure is suggested [4].

Therefore, all the cast specimens were immediately covered with polythene bags and moist cured for 2 days. At the end of the second day, specimens were demoulded and left for an additional 26 days of dry curing before testing at 28 days. No specimens were given either a wet of moist cure only for 28 days, as this would hinder the process of polymer film formation and lead to reduction in strength [4].

Tests on Fresh Concrete

Slump

The slump of latex modified concrete was determined in accordance with ASTM C143-74. The results as shown in Figures 1(*a*) and 1(*b*) indicates that the slump of latex modified concrete tends to increase with increasing water–cement ratio, polymer–cement ratio, sand–aggregate ratio and cement content.

Air Content

The air content of latex modified concrete was determined in accordance with ASTM C231-78. Results are shown in Figures 2(*a*) and 2(*b*). It can be seen that air content increases with the increase in polymer–cement ratio because of the fact that use of latex in ordinary concrete entrains a larger quantity of air due to action of surfactants contained as emulsifiers and stabilizers in polymer latexes.

Tests on Hardened Concrete

Compressive, Splitting-Tensile, and Flexural Strengths

Twelve cylindrical specimens 75 mm × 150 mm per mix were cast for compressive and splitting–tensile strength tests. The specimens were tested after 28 days according to ASTM C39-72 and ASTM C496-71 for compressive and splitting–tensile strengths, respectively.

Six small prisms 50 mm × 50 mm × 250 mm per mix were cast for flexural strength and tested at 28 days in accordance with ASTM C293-74.

DISCUSSION OR RESULTS

Strength *versus* Water–Cement (W/C) Ratio

The variation of water–cement ratio (Figure 3) has the same effect on latex modified concrete as it has on ordinary Portland cement concrete *i.e.* compressive, splitting-tensile, and flexural strengths decreases with an increase in water–cement ratio.

Strength *versus* Polymer–Cement (P/C) Ratio

Strength increases with an increase in polymer–cement ratio from 0.05 to 0.10 after which an increase in polymer–cement ratio showed a progressive decline in the characteristic strength parameters (Figure 4). The above trend has been reported by many investigators [5–7] and may be explained as follows.

1. The progressive addition of polymer changes the consistency of the mix from a dry mix to one that is just right and then to a fluid mix. Since the dry mixes yield poor specimens, the apparent strength obtained from them are low. On the contrary, the fluid mixes yield specimens containing excessive mortar and less aggregate, consequently the strength is again low. In the middle is the optimum case where the latex modified concrete is ideally workable and good specimens are obtainable.

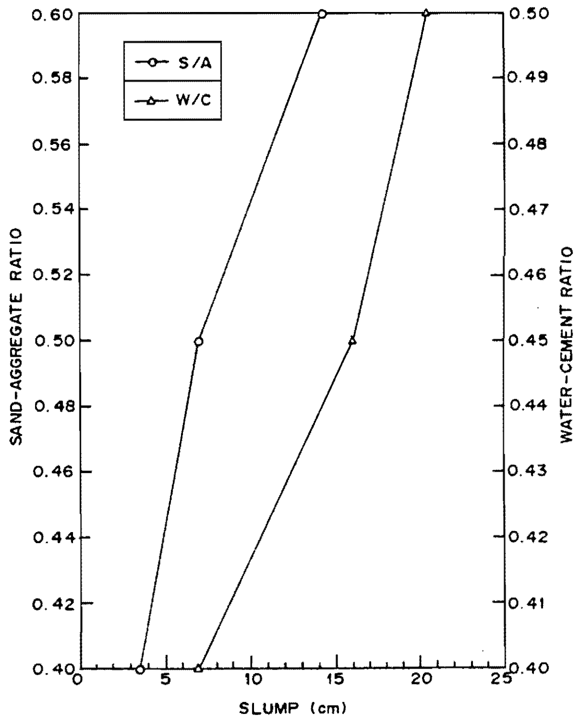

Figure 1(a). Slump versus *Water–Cement Ratio and Sand–Aggregate Ratio.*

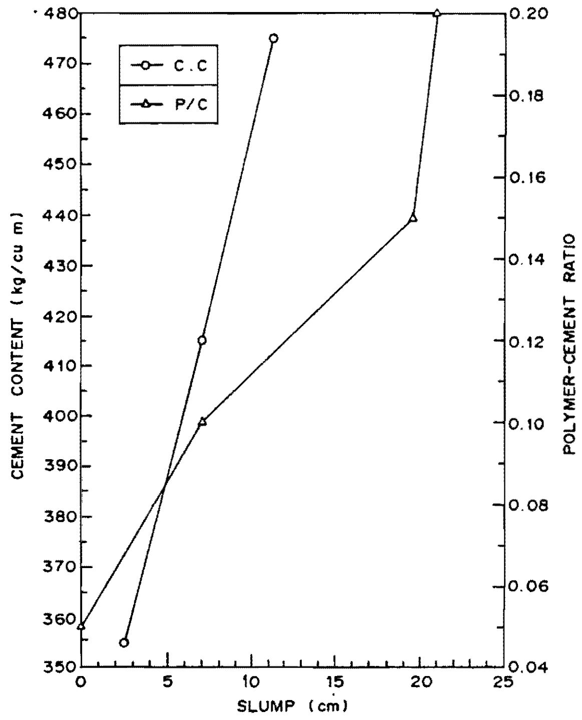

Figure 1(b). Slump versus *Cement Content and Polymer–Cement Ratio.*

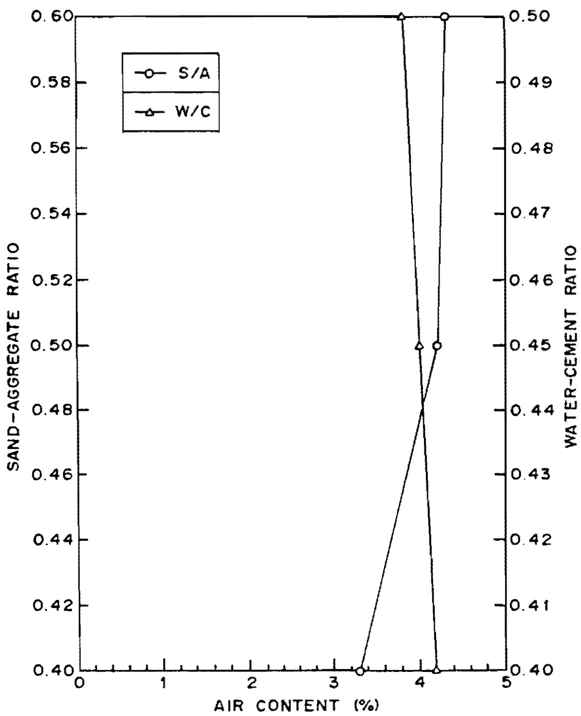

Figure 2(a). Air Content versus *Water–Cement Ratio and Sand–Aggregate Ratio.*

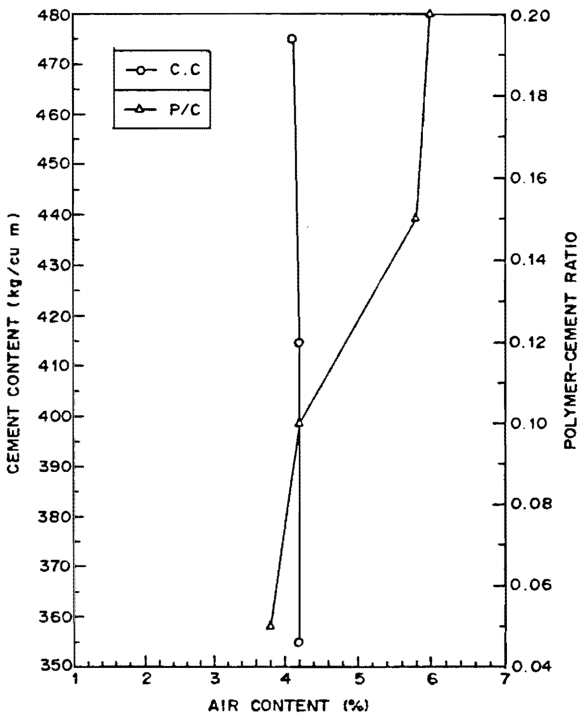

Figure 2(b). Air Content versus *Cement Content and Polymer–Cement Ratio.*

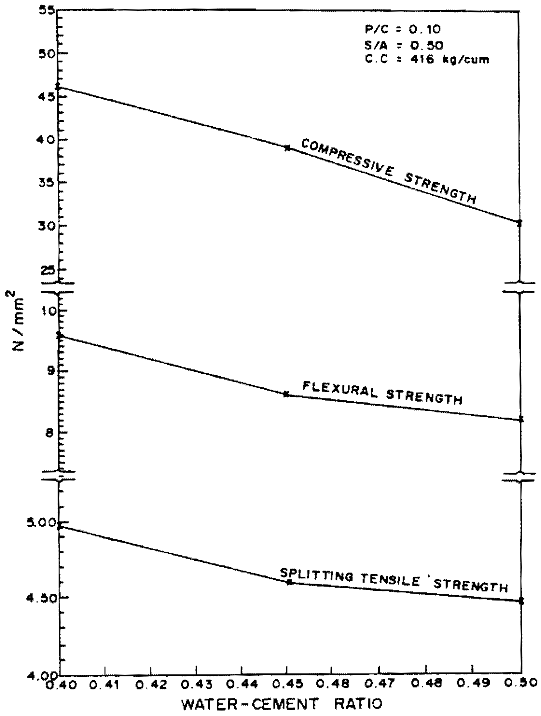

Figure 3. Strength versus *Water–Cement Ratio.*

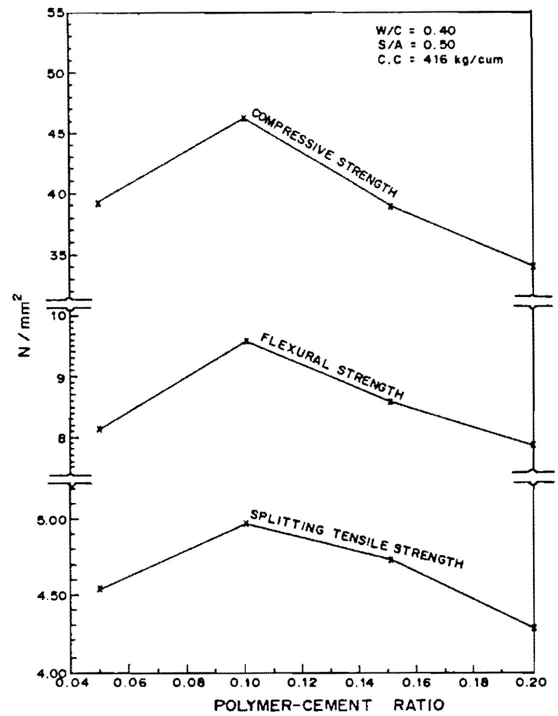

Figure 4. Strength versus *Polymer–Cement Ratio.*

2. In ordinary concrete, as the cement gel shrinks, it creates internal stresses, giving rise to micro-cracks which lower the concrete strength. However, in latex modified concrete, a continuous polymer phase is formed within the concrete matrix which bridges across the initial micro-cracks, resulting in improvement in strength. The optimum strength would be attained when there is enough polymer to form a continuous phase.

Strength *versus* Sand–Aggregate (S/A) Ratio

The variation in sand–aggregate ratio affects the behavior of concrete mixes in two ways, namely, workability, and strength. From Figure 5 it is evident that the strength of the latex modified concrete increases with an increase in the sand–aggregate ratio from 0.40 to 0.50 after which it decreases as sand–aggregate ratio is increased to 0.60. The reason for this might be that at lower values of sand–aggregate ratios the mix is quite harsh and particle interference effect is dominant *i.e.* sufficient mortar is not available to coat the particles, thereby requiring more compacting effort. At higher values of sand–aggregate ratios more surface area offered by sand requires more water for lubrication thereby increasing the water demand, which consequently lowers the strength. Thus it seems that there is an optimum value of sand–aggregate ratio which gives the best results [10].

Strength *versus* Cement Content

Strength of latex modified concrete increases (Figure 6) with an increase of cement content from 356 to 416 $kg\,m^{-3}$ but shows a gradual decline as it is increased from 416 to 480 $kg\,m^{-3}$. It is a general trend that as the cement increases the strength also increases but beyond a certain value, temperature–shrinkage cracks begins to appear in large numbers, thereby lowering the strength.

ADDITIONAL TESTS

Permeability Test

Three 200 mm cubes were cast for each of the ten trial mixes and tested for waterproofness according to German specifications DIN 1048 Part 1. DIN specifications requires the specimens to be tested at 28 days. Water pressure of 1 bar is applied for 48 hours followed by water pressures 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 penetration was measured for each sample.

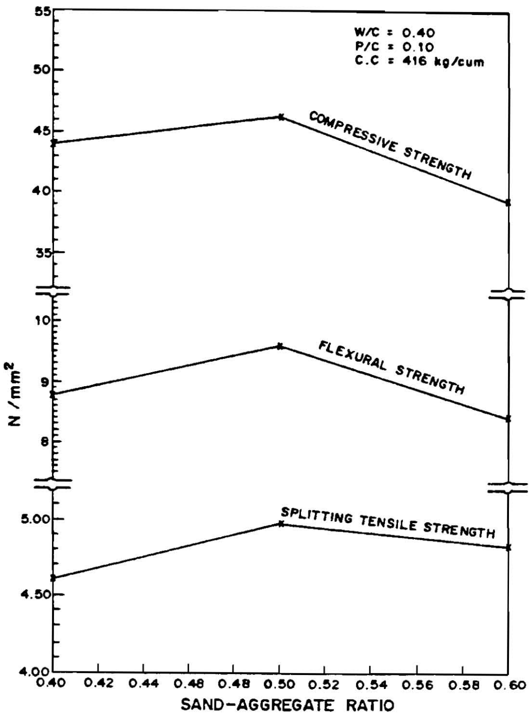

Figure 5. Strength versus *Sand–Aggregate Ratio.*

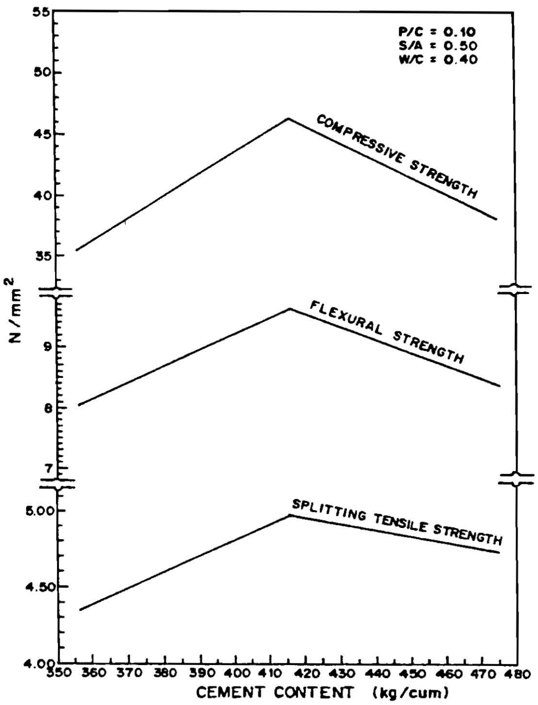

Figure 6. Cement Content versus *Strength.*

DIN specification requires that for a standard concrete, maximum depth of water penetration should not be more than 5.0 cm. As can be seen from the results in Figures 7(*a*) and 7(*b*) the maximum depth for all the latex modified concrete mixes was below this value, indicating a dense concrete.

The trend in permeability results, as a function of polymer–cement ratio, water–cement ratio, sand–aggregate ratio, and cement content follow the same pattern as the results for the three strength parameters in terms of the same variables.

Shear Bond Strength Test

Arizona slant shear test [12] was carried out to determine the shear bond strength between the normal concrete and latex modified concrete. The following procedure was adopted for the test.

1. In the first stage, half cylinders of normal concrete were cast according to the dimensions shown in Figure 8.
2. After adequate curing, these half cylinders were taken out of the water bath and their slant surfaces roughened so as to achieve a good bond between normal concrete and the latex modified concrete.
3. In the second stage, four different surface treatments were given to these half cylinders prior to pouring the latex modified concrete part. The four surface treatments investigated for maximum bond between the normal concrete and latex modified concrete were:
   (*a*) surface left dry;
   (*b*) surface kept thoroughly wet with water;
   (*c*) surface primed with latex;
   (*d*) surface primed with latex and cement slurry (1:1 by weight).

The finished cylinders were subsequently tested in compression after 28 days of casting the second stage concrete and failure was always noticed to take place along the "slant" plane adjoining the two half cylinders.

Results for the shear bond strength along failure plane, as shown in Figure 9 indicate that it is best to just keep the surface of normal concrete wet prior to pouring the latex modified concrete.

PROPOSED MIX PROPORTIONING FOR LATEX MODIFIED CONCRETE

The mix proportioning of the latex modified concrete depends on the attainment of certain optimum values for the following mix properties.

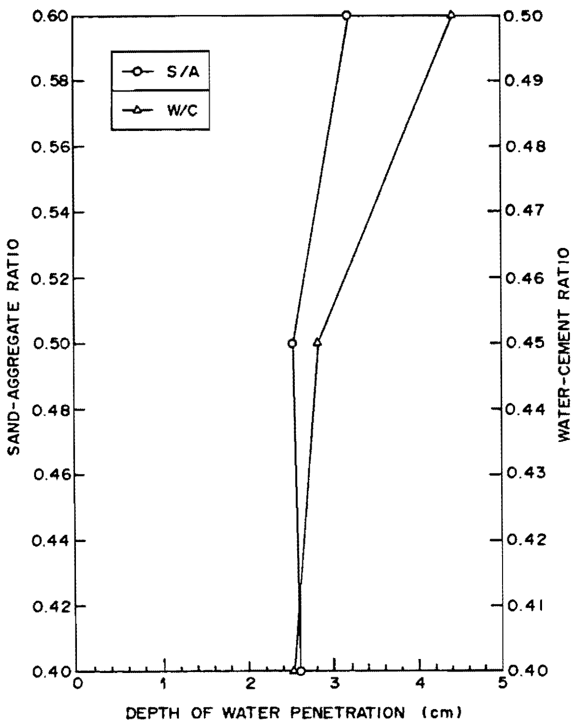

Figure 7(a). Permeability versus *Water–Cement Ratio and Sand–Aggregate Ratio.*

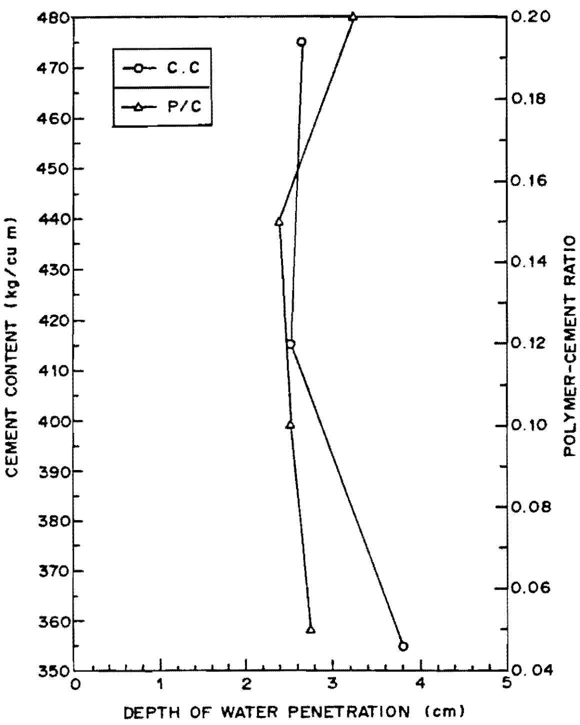

Figure 7(b). Permeability versus *Cement Content and Polymer–Cement Ratio.*

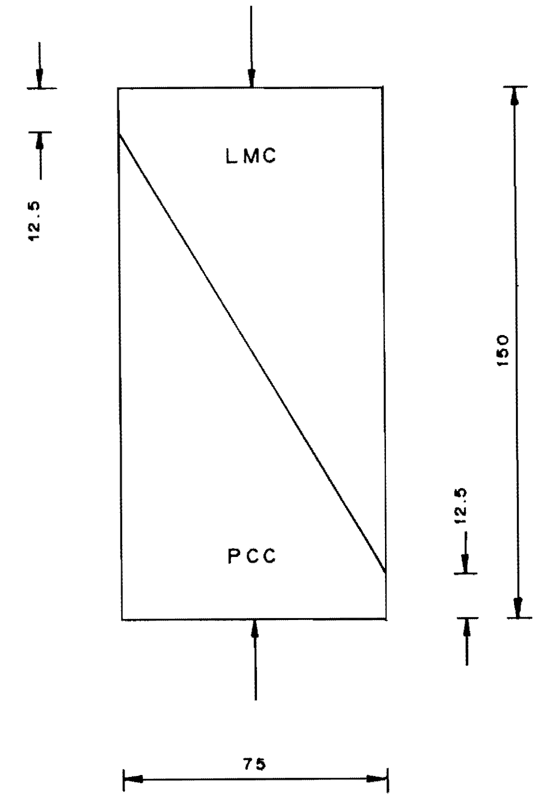

Figure 8. Composite Cylinder Dimensions (mm) for Arizona Slant Shear Test.

Slump

For a stronger concrete, good workability is required for proper placement and compaction. With latex modified concrete workability can be adjusted by proper dosage of polymer.

Strength

It is desirable to obtain high-strength concrete which can withstand internal stresses developing in the concrete due to the large differences in temperature variation in the Gulf condtions.

Permeability

The permeability of concrete is of prime importance since it determines the amount of protection provided against corrosion to the underlying reinforcement from the penetration of foreign materials like chlorides, moisture, and oxygen. In the Gulf conditions, primary sources of chlorides must be controlled at the time of mixing, along with the use

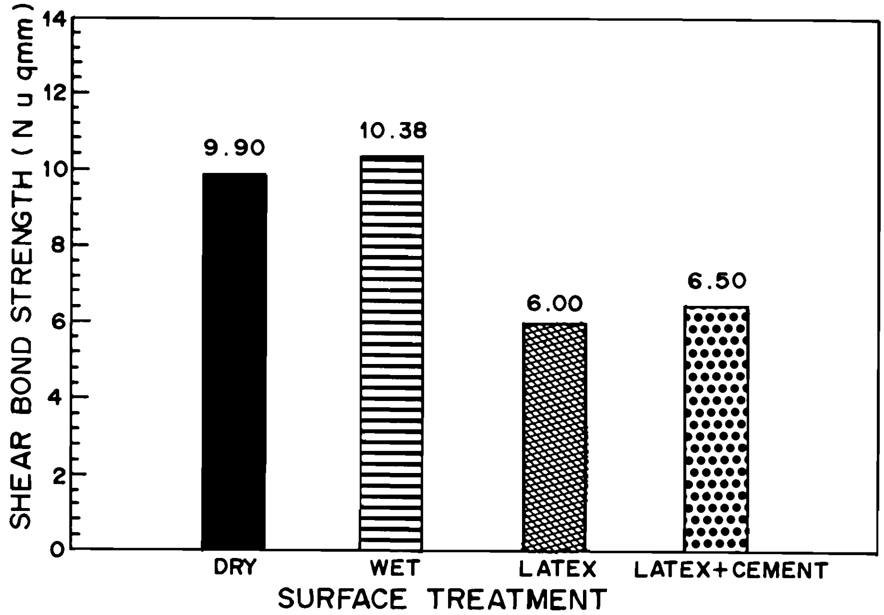

Figure 9. Surface Treatment versus *Shear Bond Strength.*

of dense concrete to prevent moisture and oxygen from reaching to the level of reinforcement, thereby inhibiting corrosion.

Based on the above criteria, the following mix proportions can be suggested for the materials used in this investigation.

Polymer–cement ratio in the range 0.08 to 0.12
Water–cement ratio in the range 0.40 to 0.43
Sand–aggregate ratio in the range 0.45 to 0.55
Cement content in the range 385 to 455 $kg\,m^{-3}$.

CONCLUSIONS

1. Based on the observations in the laboratory, it is seen that polymer–cement ratios less than 0.10 resulted in a harsh mix whereas polymer–cement ratios greater than 0.15 produce a very fluid mix.
2. A higher dosage of polymer entrains a larger percentage of air thereby affecting its strength.
3. There seems to be an optimum value of the polymer–cement ratio which gives the best results in compression, splitting-tensile, and flexural strengths. This value is approximately 0.10 for the materials used.
4. Increase in the polymer–cement ratio tends to decrease the permeability initially but any subsequent increase in polymer–cement ratio above 0.15 increases the permeability.
5. An excessive dosage of polymer, in addition to being uneconomical, tends to have an adverse effect on the properties of latex modified concrete and should therefore be avoided.
6. Slant shear test results have shown that the use of wet surface treatment given to the normal concrete surface yields the best results for bonding latex modified concrete to hardened Portland cement concrete.

FUTURE RESEARCH PROGRAM

Future ongoing research work is aimed at the study of effectiveness of LMC overlay as a protective system against corrosion of reinforcement. Three panels (1500 mm × 750 mm × 150 mm) of PCC with different thicknesses of the LMC overlay (25 mm, 40 mm, and 50 mm) and one panel of PCC alone has been cast. These panels are being subjected to ponding with sodium chloride solution, and monitoring of the corrosion process is being carried out by measuring the half cell potential and chloride profiles across the depth of the panels.

The use of latex modified concrete overlays in the Kingdom environments requires investigation the effect of the large temperature variations on latex modified concrete as a protective system against corrosion. Twelve 200 mm cubes are being subjected to different number of heat cycles (60, 90, and 120) and then tested for permeability. A heat cycle in this investigation constitutes heating the specimens up to 80°C for 6 hours and cooling them for another 6 hours.

The use of latex modified concrete as a bridge deck overlay requires its endurance under fatigue loading. Six beams (900 mm × 300 mm × 150 mm) are being tested with the overlay in compression and tension to quantify the composite behavior of these beams under cyclic loading.

The above results will be presented in a subsequent paper.

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Paper Received 30 May 1988; Revised 28 November 1988.