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Strength and Durability of Styrene –Butadiene Latex Modified Concrete with Silica Fume

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Abstract*: *This paper discussed the properties of styrene butadiene rubber (SBR) latex modified concrete. The latex modified concrete using SBR latex were prepared with various polymer-binderratios and tested for compressive strength, flexure strength, elastic modulus and rapid chloride penetration test. Latex contents were varied as 5, 10 and 15 percentages by mass of binder (cement and silica fume). The effect of the polymer-binder ratio on the properties of latex modified concrete was examined. It was concluded from the test results that the compressive strength and elastic modulus decrease with polymer binder ratio and flexural strength increasing with polymer binder ratio. Addition of latex reduces the chloride ion penetration due to latex film formation..

Keywords*: *Latex modified concrete, SBR, Silica Fume, compressive strength, flexural strength, flexural Rapid chloride test durability.

I. INTRODUCTION

Various latex materials have been developed and marketed, they were used in mortars, but in recent years their use has extended to concrete. Latexes used include vinylidene chloride, styrene butadiene, polyvinyl acetate and acrylics. Addition of latex and in concrete alters the mechanical and durability properties of the concrete mixtures.

Latex is polymer system formed by the emulsion polymerization of monomers and it contains 50% solid by weight. Since mechanical properties, hydration process in cement and durability of concrete are highly dependent on the state of microstructure. Previous research studies have shown that the polymer as modifier is promising in improving micro-structure of concrete. Consequently the properties of LMC are improved over the conventional concrete.

Since conventional concretes often fail to prevent the intrusion of moisture and aggressive ions adequately, special concretes with low permeability are needed.

Latex modified concrete have widely been used as construction material for various application such as overlays in bridge decks, floor, paving, water proofing and repairing material because of their satisfactory performance. Silica fume has recently been used for improving the mechanical properties and durability of cement concrete. The present paper deals with the properties of polymer modified concrete with silica fume, which is added to the concrete for the purpose of improving their properties.

The Latex modified concrete containing styrene butadiene rubber (SBR), prepared with various polymer binder ratios with 8 % silica fume content by mass of cement, and tested for compressive and flexural strength, Elastic modulus of the concrete. The effects of the polymer and silica fume content on the properties of the polymer modified concrete were examined.

This study is part of a comprehensive investigation carried on the use of polymers in concrete. The main objective of the study was to investigate and evaluate the main durability aspects of Styrene –Butadiene latex modified concrete (LMC) compared to those of conventional concrete.

II. PROPERTIES OF THE MATERIALS

Cement: Ordinary Portland cement of 43 grade confirming to IS 8112:1989.Physical properties of the cement are shown in Table 1.

Table 1: Physical Properties of cement

Property	Value
Specific gravity	3.15
Initial setting time	75 min
Final setting time	200 min
Compressive strength at 28 days	48.4 N/mm^2

Fine Aggregate: Natural River sand passing through 4.75mm IS sieve having fineness modulus 3.12, specific gravity 2.61 and confirming to Zone III of IS 383:1970.

Coarse aggregate: Crushed stone with a nominal maximum size of 20mm having fineness modulus 6.86 as per IS383:1970.

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Polymer Latex: Styrene Butadiene copolymer Latex manufactured by Fosroc India limited.

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Table-2 - Mix Proportions

S.No	Mix Details		Cement kg/m^3	SF kg/m^3	FA kg/m^3	CA kg/m^3	W/B ratio	P/B ratio	% of water adjusted	Slump in mm
1	C	Control	425.73	0.00	672.09	1122.42	0.45	0.00	0.00	50
2	CL5	5% Latex	425.73	0.00	671.27	1121.05	0.40	0.05	5	55
3	CL10	10%Latex	425.73	0.00	670.43	1119.66	0.35	0.10	10	65
4	CL15	15%Latex	425.73	0.00	672.37	1124.31	0.30	0.15	15	75
5	CL5SF8	5%Latex +8%SF	391.63	34.10	657.55	1106.10	0.42	0.05	0.00	53
6	CL10SF8	10%Latex +8%SF	391.63	34.10	647.07	1088.49	0.40	0.10	0.00	55
7	CL15SF8	15%Latex +8%SF	391.63	34.10	646.04	1087.07	0.35	0.15	5	55

W/B-Water Binder ratio, **P/B-**Polymer Binder ratio

Silica Fume (SF): Mineral admixture obtained from ELKEM INDIA (P) Ltd, confirming to ASTM-1240.Specific gravity 2.2

Colour : Milky white emulsion pH: 8.5

Specific gravity 1.01

Total polymer solids: 50%

Materials addition and replacement:

- Latex -5%,10%,15% addition
- Silica Fume 8% Replacement of Cement

Mix Design

In this study concrete mix M_{30} was considered as control concrete (C).The mix design for the above grade of concrete as done based on IS10269:2009 for the workability range of 50-75mm. The control concrete mixture was comprised of Portland cement, water, coarse and fine aggregate. The mix proportion of control concrete mix is presented in Table 2Latex modified concrete (LMC): In this research latex modified concrete composition containing 5 %(CL5), 10 %(CL10) and 15% (CL15) SBR latex by mass of cement were prepared by modifying control concrete. Since the SBR latex used in this study contained 50%of water required to be added in the concrete was accordingly adjusted. Some additional percentage of water to mass of binder also adjusted to maintain the slump between 50-75mm. Additional percentages of water content adjusted (reduced) is shown in the Table 2. Silica fume (SF) of 8% by mass of cement added with latex modified concrete to explore the possibility of strength reduction which may take place due to the latex addition. Concrete mixtures of three were designed with latex modification and three mixtures of latex and silica fume (CL5SF8, CL10F8, and CL15SF8).

Table 2: Mix proportions of concrete

Note: W/B-Water binder ratio, **P/B**-Polymer binder ratio

Test Details

The weighed ingredients for the batch were mixed in a tilting drum type concrete mixture machine. The test specimens for compression (150 x 150 x 150mm cube), flexural strength (100 x 100 x 500mm prism), and modulus of elasticity of the concrete (150mm dia x300mm height cylinder),and 125x250x3200mm beams were cast in steel moulds with mould releasing agent applied. The fresh concrete mix was filled in the steel mould in three equal layers and each layer was well compacted using table vibrator. Before the initial setting time of the concrete, top surfaces of the specimens were levelled using finishing trowel. The conventional concrete specimens were demoulded after 24 hours of casting and then moist cured for 28 days. The curing of latex modified concrete should be such that both hydration of cement and polymer formation take place yielding a strong co-matrix of hydrated cement inter penetrated by polymer film. While the hydration process is promoted by presence of moisture, film formation takes place only on drying. Therefore, the curing protocol for LMC specimens involves a combination of moist curing to promote cement hydration followed by drying to promote film formation. The latex modified cement concrete specimens were subjected to 2 days moist curing, 5 days water curing and 21 days air curing.

III. EXPERIMENTAL INVESTIGATIONS

Mechanical Properties of Latex modified concrete:

Compressive Strength

The compressive strength tests were conducted on a compression testing machine as per IS: 516-1959.The cubes 150mm size were tested at the ages 7days,28 days,56 days and 90 days. For each concrete composition three specimens were tested. Average value of three samples has been reported as compressive strength in Table 3.

Table 3: Results of Compressive Strength

S. No	Mix Details	Average Compressive Strength N/mm^2		
		28Days	56Days	90Days
1	C	38.65	42.00	43.90
2	CL5	35.28	38.21	40.21
3	CL10	33.00	35.67	38.28
4	CL15	29.81	32.49	34.78
5	CL5SF8	36.74	39.38	42.38
6	CL10SF8	34.65	37.69	40.64
7	CL15SF8	32.00	35.64	37.86

Flexural Strength

Concrete specimens of size 100mmx100mmx500mm were tested under standard four points bending in flexural testing machine. Specimens were tested at different ages. The flexural strength was calculated as the average of the three tested specimens and shown in Table 4.

Table 4: Results of Flexural Strength

S. No	Mix Details	Flexural Strength N/mm^2		
		28Days	**56Days**	**90Days**
1	C	4.50	4.80	5.00
2	CL5	4.83	5.20	5.46
3	CL10	5.10	5.36	5.76
4	CL15	5.46	5.86	6.25
5	CL5SF8	4.95	5.36	5.65
6	CL10SF8	5.45	5.94	6.37
7	CL15SF8	5.67	6.30	6.70

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Modulus of Elasticity

Cylindrical specimens of size 150mm diameter and 300mm height were used for the determination of modulus of elasticity as per IS: 516-1959.Concrete mixes with 10% latex content provided the average strength development for both compression and flexural strength. Hence elastic modulus test conducted for selected mix CL10 only. Specimens were loaded uniaxial in a compression testing machine and deformations were recorded using dial gauge of 0.01mm least count at an interval of 10kN until the peak load.

Stress strain curves obtained from cylinder compressive strength test were shown in Figure 3. The elastic moduli of the selected concrete mixes are shown in Table 5.

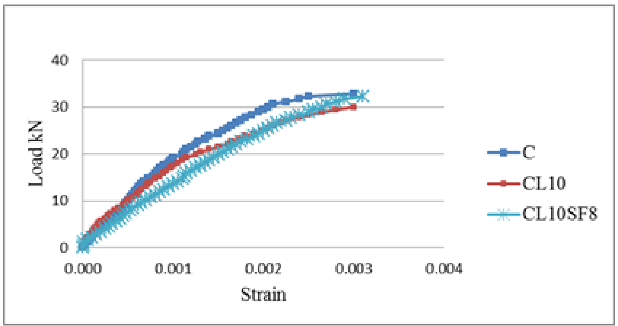

Fig. 3: Stress Strain Curve

Table 5: Elastic Modulus of Concrete Mixes at 28 days

S. No	Mix	Elastic Modulus N/mm^2
1	C	33333
2	CL10	26666
3	CL10SF8	22857

Water Absorption in Hardened Concrete

This test method covers the determinations of density, percent absorption and percent voids in hardened concrete. The water absorption test were carried out by casting cubes of dimension 150mmx150mmx150mm were cast and cured for the period of 28days.After 28days of curing specimens were taken out and dried in oven to dry at the temperature of 105C to remove the moisture content. Dry weight of the specimens was measured (W1). Afterwards they were immersed in water for 24 hours to study the water absorption.. After completion of 24hours the specimen were weighed (W2), from these values the water absorbed by all the specimens were calculated are given in table 6.

Percentage of Water absorption= ((W2-W1)/W1) x100

Table 6 Percentage of water absorption

S. No	Mix	Percentage of water absorption
1	C	4.50
2	CL10	2.87
3	CL10SF8	2.50

Sulphate Resistance:

To conduct the Sulphate attack studies in the present investigation immersion techniques was adopted. 150mm size cube specimens are taken out from after 28 days of curing then the cube specimens are allow to dry and the initial weight was measured (W1). Then 5% Na_2SO_4 salts are mixed per liter of distilled water. Cube specimens are then immersed completely in the sulphate solution for 30day.The solution was kept at room Temperature and the solution was stirred regularly, at least twice a day to maintain the uniform solution. After 30 days the cube specimens are taken out from the sulphate solution and kept dried. Then the specimens are weighed (W2) for calculating the percentage weight loss. The compressive strength of specimens immersed in solution Na_2SO_4 about 30 days are presented in Table.7

Fig.4Sulphate resistance test

Table 7 Test Results Sulphate Resistance Test

S.No	Mix	Compressive strength of specimen immersed in Na_2SO_4 solution (N/mm^2)	Percentage compressive strength loss	Percentage weight loss
1	C	33.92	12.23	1.1
2	CL10	30.18	8.55	0.58
3	CL10SF8	32.12	7.30	0.52

Acid Resistance of Concrete

To perform he acid attack studies in the present investigation immersion technique was adopted. After 28days curing 150mmx150x150mm cube specimens were immersed in Hcl and H_2so_4 of percentage 3% solution as shown in fig.8.The solution was kept at room temperature and solution was stirred regularly,at least twice a day to maintain uniformity .The solution was replaced at regular intervals to maintain concentration of solution throughout the test period .The evaluation were conducted after 30days from the date of immersion. After removing the specimens from solution, the surface were cleaned with a soft nylon wired brush under running tape water to remove weak product and loose material from the surface. The specimens were allowed to surface dry and the compressive strength of specimens was found out and the average percentage of loss of weight and compressive strength were calculated present in the Table.8, 9.

Fig5 Specimens immersed in diluted Hcl and H_2so_4

Table 8: Test Results of Acid Resistance Test

S. No	Mix	Compressive strength of specimen immersed in H_2SO_4 solution (N/mm^2)	Percentage compressive strength loss	Percentage weight loss
1	C	26.92	30.35	1.64
2	CL10	24.84	24.73	1.2
3	CL10SF8	27.02	22.00	1.12

Table 9 Test Results of Acid Resistance Test

S.No	Mix	Compressive strength of specimen after immersion in Nacl solution (N/mm^2)	Percentage compressive strength loss	Percentage weight loss
1	C	34.15	11.64	4.0
2	CL10	30.22	8.42	1.0
5	CL10SF8	32.43	6.41	0.66

Salt water immersion Test

Salt water immersion test was performed to evaluate the resistance of the concrete cubes subjected to salt water attack which might have resulted from Nacl. The volume of expansion induces stresses which may generate internal cracks and ultimately load to failure. The concrete specimen cubes of 150x150x150mm size were cast for finding the weight loss and strength loss due to the salt attack. The cubes were cured for 28 days. After measuring the weight of the specimen, they were immersed in water diluted with 3.5% sodium chloride and 5% sodium sulphate solution. After 28 days of continuous immersion the cubes were taken out and dried at room temperature for 24 hrs then they were lightly brushed to remove the debris from the surface before weighing. The specimens were allowed to surface dry and the compressive strength of specimens was found out and the average percentage of loss of weight and compressive strength were calculated present in the Table.10

Table 10: Salt water resistance test results

S. No	Mix	Compressive strength of specimen after immersion in Nacl solution (N/mm^2)	Percentage compressive strength loss	Percentage weight loss
1	C	34.15	11.64	4.0
2	CL10	30.22	8.42	1.0
5	CL10SF8	32.43	6.41	0.66

Rapid Chloride Permeability Test

To verify the high degree of resistance to chloride penetration of the SBR latex modified concrete and comparison with conventional concrete.

This test covers the determination of the electrical conductance of concrete to provide indications of its resistance to chloride ions.

Disc shaped test specimens of size 100 mm dia x 50mm thickness cut from the 100mm x 200mm cylinder were used for chloride diffusion studies as per

ASTM C1202.The diffusion cell considered of two transparent chambers and was specially fabricated for the test on one side chamber I of the test set up contained Nacl solution (concentration 3.0m).The chloride ions from chamber I was forced to enter chamber II through the centrally placed concrete specimens, under effects voltage as well as difference in concentration of chloride ion on either side of the specimen. Observations were made over a period of 6 hours under an electric voltage of 60V and total charge passed was calculated. Rate of chloride penetrations at the age of 28 days were shown in Figure 6 and in Table 11.The total charge passed is presented in Table.12

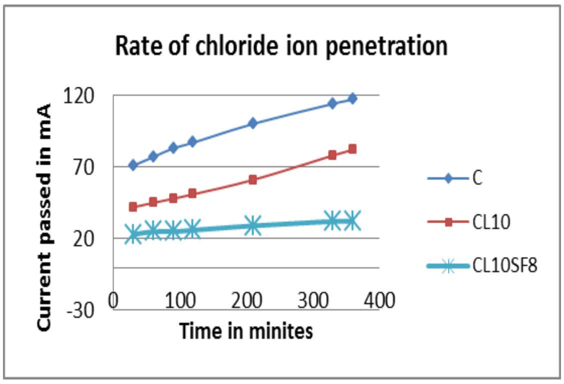

Fig. 6: Rate of Chloride ion Penetration

Table 11: Rate of Chloride ion Penetration

S.No	Time in mnts	Current passed in mA		
		C	CL10	CL10SF8
1	30	71	42	23
2	60	77	45	25
3	90	83	48	25
4	120	87	51	26
7	210	100	61	29
11	330	114	78	32
12	360	117	82	32

Table 12:Total Charge passed

S.No	Mix	Charge Passed (Coulombs)	Reference value as per ASTMC1202	Chloride ion Pernetrability
1	C	1839.93	1000-2000	Low
2	CL10	1148.52	1000-2000	Low
5	CL10SF8	536.09	100-1000	Very low

IV. RESULT AND DISCUSSION

Slump test

Slump test were performed on both control and latex modified concretes. However percentage of water content is adjusted (decreased), from the results it was observed that, the addition of SBR increases slump.

This shows that SBR latex has plasticizing effect due to which workability of concrete increased and maintained between 50mm to 75 mm.

Compressive Strength

The compressive strength of control concrete, latex modified concrete and latex modified concrete with silica fume containing different percentage of SBR were presented.

It was observed that the latex modified concrete specimen showed 28 day average compressive strength of the order 35.28 N/mm^2, 33 N/mm^2, 29.81 N/mm^2 at the latex content of 5%, 10%, and 15% respectively. Latex modified concrete with silica fume showed average compressive strength of order 36.74 N/mm2, 34.65 N/mm2, 32 N/mm2 at latex content of 5%, 10%, and 15% respectively, while the control concrete specimens had average compressive strength of 38.65 N/mm2. It could be observed from results that the compressive strength of concrete generally followed a decreasing trend with the increase of the latex dosage. The compressive strength at 28 days decreased 8.72%, 14.61%, 22.87% at the latex content of 5%, 10%, and 15% respectively. The compressive strength of latex modified concrete with silica fume decreased 4.94%, 10.35%, 17% at the latex content of 5%, 10%, and 15% respectively at 28 days. A Similar reduction trend was observed in compressive strength at 56 days and 90 days cured specimens. At 56 days 9%, 15%, 22.64%, 6.23%, 10.26% and 15.14% compressive strength reduction were observed at the latex content of 5%, 10%, and 15% of latex for LMC and LMC with silica fume respectively with respect to 56 dayscontrol specimens. The compressive strength reductions at 90 days were 8.4%, 12.80, 20.77%, 3.46%, 7.42% and 13.75% for LMC and LMC with silica fume respectively with respect to the 90days control specimens. The reduction in compressive strength of latex modified concrete is due to the presence of rubber content as soft inclusion in the cement gel particles and increase in air content of latex modified concrete. Latex modified concrete with silica fume improved the compressive strength of concrete compared to latex modified concrete. Physical interaction occurred due to the fineness of silica, its large specific surface and that its particles fill the existing spaces between the various granules of cement and those between the cement paste and the sand, which act as a filler reducing porosity cement matrix a densified structure and hence improvement in compressive strength. The decrease in compressive strength due to latex addition can at least be compensated by 3.78%, 4.28%, and 5.87 % by the addition of silica fume in latex modified concrete with latex content of 5%, 10%, and 15% respectively at 28 days.

Flexural Strength

Addition of 5%, 10% and15% latex in latex modified concrete increases the flexural strength to 7.33%, 13.33% and 21.3% respectively at the age of 28 days. The Latex modified concrete with silica fume showed an improvement of 10% ,21%, and 26% at the latex content of 5%,10% and 15% respectively at the age of 28 days. At 56 days 7.7%, 11.67%, 22.08%, 11.66%, 23.75% and 31.25% flexural strength improvement were observed at the latex content of 5%, 10%, and 15% of latex for LMC and LMC with silica fume respectively. The flexural strength developments at 90 days were 9.2%, 15.25, 25%, 13%, 27.40% and 34% for LMC and LMC with silica fume respectively. A Significant flexural strength change was observed that mainly due to improvement in cement hydrate and aggregate bond because of decrease in w/B ratio and the high tensile strength of latex films present in latex modified concretes. Flexural strength depends mainly on the adhesion of aggregate grains and cement matrix. For latex modified concrete, creation of polymer membrane has a double role, that is increase the adhesion between the aggregate grains and cement matrix; and prevent progressive development of initial micro cracks due to its elasticity.

Elasticity modulus

Stress strain characteristics of latex modified cylindrical specimens in compression obtained from load controlled tests compared to the control mix. It was observed that the stress strain plot of latex modified concretes were more deformability and similar trend to that of control specimens. The latex modified concrete and LMC with silica fume showed lower moduli compared to control concrete. Consequently latex modified concretes provided a lower elasticity than unmodified (control) concrete. Compared with control concrete the LMC and LMC with silica fume showed 20%, 31% reduction in elastic modulus with 10% latex content at the age of 28 days. The deformability and elastic modulus of the latex modified concrete tend to increase and decrease, with the addition of latex.

Water absorption test results

Due to the good pore structure in the concrete mix containing polymer and silica fume shows resistance to water absorption is high. The reason behind this high resistance is due to reduction in voids in pore structure of concrete. Mix with Latex are shows better resistance to water absorption compared to all other mix. The latex decreases the 24 hours water absorption by 36%.and combined addition of latex decrease the water absorption by 46 %

Sulphuric acid attack

It is observed that specimens immersed in a dilute sulphuric acid solution undergoes some deterioration in their surface and it is found that latex modified concrete with silica fume showed good resistance to sulphuric acid attack compared to mix. The loss of compressive due to sulphate attack are 30.35% ,24.73% ,22.0% respectively for the concrete mixC,CL_{10},CL10SF_8compared to compressive strength of concrete specimens without exposure to sulphate acid attack. The mix contain Latex with silica fume showed excellent performance against attack of sulphuric acid and exhibit better compressive strength and weight loss compared to control concrete.

Hydrochloric acid attack

The mix with polymer shows better ability to resists the hydrochloric acid attack. The loss of compressive strength due to hydrochloric acid attack are 11.64%,8.42%,6.41%respectively for the concrete mix C,CL10, CL10,SF8, compared to compressive strength of concrete specimens without exposure to hydrochloric acid attack. More over concrete mix with Latex and silica fume also show good resistance to acid attack. The mass losses due to hydrochloric acid attack are 4.0%, 1.0%, 0.66% for respective concrete mix. The mix with polymer and silica fume showed better resistance
acid attack

Sulphate resistance test

The loss of compressive strength for C, CL10%, CL10SF8 are12.23%, 8.55%, 7.30.The loss of weight is also greatly reduced for concrete mix with polymer only.

But mix with Latex and silica fume showed better resistance to sulphate than concrete mix without latex and silica fume. The deficiency may be obtained in control concrete will easily overcome by the addition of latex and silica fume.

Salt resistance test

The mix with polymer shows better ability to resists the sodium chloride attack. The loss of compressive strength due to sodium chloride attack are 11.64%,8.42%,6.41% compared to concrete specimen without exposure to sodium chloride attacks. More over concrete mix with latex and silica fume showed good resistance to sodium chloride attack. The losses of weight due to sodium chloride attack are 11.64%, 8.42%, 6.41% respectively for mix for C, CL10%, CL10SF8.

Rapid Chloride Permeability

The results show that the Styrene –Butadiene latex modified concrete (LMC) shown satisfactory performance in the chloride permeability.

The LMC provided greater resistance to penetration of chloride ion which is very important from the point of view of corrosion. A special concretes with latex and latex with silica fume is expected to provide the low level of permeability needed for long lasting service that are not attainable with traditional concrete. Compared with control concrete LMC and LMC with silica fume reduced the chloride iron penetration to 37.5 % and 71% respectively.

V. CONCLUSIONS

Latex modified concrete was developed focusing on the workability, strength development and durability. This study showed the effect of latex modification in mechanical property of latex modified concrete. The main variables were latex content 5% to 15% .The conclusions are as follows.

(i) Latex addition allows w/c ratio to fall by 0.05 to 0.15 without affecting the workability in all cases studied. It is expected that such fall in w/c ratio should increase strength more appreciably in the lower w/c ratio than higher w/c ratio. But it is observed that concrete in the lower w/c ratio has reducing effect of latex addition on compressive strength that the corresponding reduction in w/c ratio cannot compensate this effect.

(ii) The reducing effect of latex addition on compressive strength of latex modified concrete could be attributed to incorporation of soft rubbery material in the matrix. Maximum reduction of compressive strength 22.87% at 28 days was observed at 15% latex addition in LMC.

(iii) Flexural strength increased with the increase of polymer binder ratio. Maximum increase of flexural strength was 21at 15% latex addition for LMC at the age of 28 days. Flexural strength increased with the increase of polymer binder ratio.

(iv) Elastic modulus decreased over unmodified concrete tendency is in agreement with increased deformability of latex modified concrete over unmodified concrete. The elastic modulus reduces by 20%for LMC

(v) Because of the water reducing effect of styrene butadiene latex the porosity and effective chloride ion decreases. Improved durability property of in respect of resistance to chloride ion resistance is due to latex film interpenetrating into hydrated cement gel.

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