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# INFLUENCE OF SBR LATEX ON LONG-TERM DEFLECTION OF HSC BEAMS

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**Abstract:** Using resins in concrete enhance a series of interesting properties such as high erosion resistance to chemical substance such as acids, mechanical properties, frost resistance, impervious to liquids, dampen vibrations, and many other properties. This paper discusses experimentally the effect of SBR Latex into concrete short and long-term deflection of latex modified concrete beams under sustained long-term service loads, effect of SBR latex on compressive strength, and the density of concrete. Four beams were cast and tested with dimensions (150×150×750) mm; the experimental parameters included was the replacement ratio of SBR added (0, 5, 10, 15) %, and the concrete strengths. The test results showed that the trend of long-term performance of concrete beams was comparable to those without SBR Latex. Furthermore, the test results showed that with the increase of SBR ratio, the compressive strength and the long-term deflection multiplier were reduced.

**Keywords:** *Polymer Concrete, SBR Latex, High Strength, Beams, Long and Short -Term Deflection*

## تأثير المضاف ستايرين بيوتادين مطاط(SBR) على الهطول طويل الامد للعتبات الخرسانية عالية المقاومة

**الخلاصة:** استعمال البوليمر في الخرسانة له فوائد كثيرة في تعزيز بعض الصفات كزيادة مقاومة التاكل ضد المواد الكمياوية ومقاومة التجمد والعوامل الجوية و تقليل نفاذيتها للسوائل ومقاومة الاهزازات وغيرها من الصفات.في هذا البحث تم دراسة تاثير استعمال البوليمرات على خواص الخرسانة لكل من الهطول القصير الامد والطويل الامد عمليا ، حيث تضمن برنامج العمل صب عتبات خرسانية مطورة بالبوليمر نوع (Latex) وتسليط احمال مستمرة عليها لمدة اكثر من سنة.كما تم دراسة بعض الخواص الهندسية للخرسانة مثل الكثافة ومقاومة الانضغاط.تم فحص (4) عتبات بابعاد 150×150×750 ملم ،وكان المتغير الرئيسي في هذه الدراسة هو محتوى البوليمر كنسبة ابدالية من وزن السمنت (0% المرجعية ، 5% ، 10% ، 15%) حيث تم تقليل كمية السمنت وتعويضها بالبوليمر ليكون نسة المواد الاسمنتية (cementitious) ثابتا في كل الخلطات.بينت الفحوصات ان استعمال البوليمر زاد من كثافة الخرسانة. كما بينت ان زيادة نسبة البولمر ادى الى نقصان مقاومة الانضغاط للخرسانة مما ادى الى زيادة في الهطول القصير الامد على عكس الهطول الطويل الامد فقد دلت النتائج انه بزيادة نسبة البوليمر ادى الى نقصان مضروب الهطول.

## 1. Introduction

ACI 548.3[1] define the Polymer-modified cementitious mixtures (PMC) as hydraulic cement combined at the time of mixing with organic polymers that are

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dispersed or redispersed in water, with or without aggregates. Prediction of deflection of un-modified reinforced concrete (RC) elements is a complex problem including a wide range of material properties, such as the different strength and deformation properties of steel and concrete, cracking, tension softening and tension stiffening, as well as creep and shrinkage. It is not surprising that due to the highly complicated behaviour of RC, different deflection prediction techniques are used in the design codes of different countries. At sustained loading, the effects of latex makes the problem of deformation analysis even more challenging.

## 2. Effect of SBR Latex on Concrete Compressive Strength

Many researchers worked on the effect of polymer on the compressive strength of concrete. Mohmedet.al.[2] studied the influence of SBR latex and Polyvinylidene Chloride (PVDC) on mechanical properties of High Performance Concrete (HPC), Standard cube specimens of 100 mm were cast and cured for 90 days for obtaining the compressive strength at 7, 28 and 90 days. After obtaining the certain strength for nominal high performance concrete through trial mixes and fixing the dosages of the polymer proportion, modified high performance concrete specimens were produced by adding different types and contents of polymers.

The test results of the compressive strength at 28 days indicate that the additions of 1.5% and 3% of the SBR from cement weight resulted in an increase of approximately 16% and 6% in the compressive strength respectively, while the content of 5% SBR led to a slight decrease of approximately 1.35%. Additions of 1.5%, 3% and 5% of the PVDC to the mixes increased the compressive strength by 13.6%, 9% and 11%, respectively.

Al Numan [3]studied the structural behavior of polymer modified reinforced concrete (PMC) beams with Styrene Butadiene Rubber (SBR) polymer including compressive and flexural strength. Two series of concrete mixtures were used; the first was with moderate compressive strength (level I, with 2 SBR ratios, 0 and 5%) and the other with compressive strength higher than the former (level II, with 2 SBR ratios, 0 and 3%). Two reference mixes were made also for comparative purposes. Eight beams are moulded of (95×200×1600mm) dimensions with different steel reinforcement ratio (ρ). Load-deflection relationships of beams made of polymer modified concretes and references concretes, the moment at mid-span with deflection, and moment-curvature relationships were established. The results showed that PMC beams have a stiffer response in terms of structural behavior; more ductility and lower cracking deflection than those observed on reference concretes, and that refer to good role of styrene Butadiene Rubber (SBR) polymer on the properties and behavior of reinforced concrete beams.

The results also showed that PMC compressive and flexural strengths were more than reference mixes, that’s probably because the SBR used is added to the mixture without cement replacement and its water was considered within the mix water requirements.

Melkundi and Halhalli [4]studied the behavior of convectional M25 Grade concrete, SBR-latex combined with M25 concrete, steel fiber combined with M25 concrete, and SBR-latex modified steel fiber reinforced concrete. The experimental study made to obtain strength characteristics of above matrix in compressive strength, split tensile and flexural strength. It is observed that the concrete added with fiber and latex behaved much better with regards to higher first crack load and ultimate load, also lesser deflection. This is due to compactness achieved due to latex and fiber filling in concrete matrix. Among the four mixes in this investigation, namely M25, SBR+M25, SF+M25 and SBR+SF+M25, the compressive strength obtained at 28 days are 33 MPa, 26.16 MPa, 35 MPa and 32 MPa respectively. In case of SBR-latex modified concrete there is decrease in compressive strength. This is due to lower density of latex with regards to matrix density (mix rheology), while the combination of SBR-latex and steel fiber showed an increase in compressive strength.

Fang et. al. [5]studied the influence of PolyPropylene (PP) Fiber and SBR Latex on the Mechanical Properties of Crumb Rubber Mortar, they presented a new kind of rubber mortar modified by PP fiber and Styrene-Butadiene Rubber latex (SBR latex). The compressive strength, flexural strength, flexural toughness, and flexural elasticity modulus of this crumb rubber mortar were investigated. The results also showed that the flexural toughness index of the rubber mortar enhanced by about 50–100% with the addition of PP fiber and SBR polymer latex.

Due to the addition of PP fiber and SBR latex, the flexural elastic modulus of rubber mortar could further reduce by 4- 27%. Furthermore, it was observed from scanning electron micrograph (SEM) that the interfacial transition zone between the rubber particles and cement paste was enhanced by the SBR latex, and the interleaving of polymer films and rubber particles strengthen the flexibility and toughness of the mortar. Compared to the rubber mortar samples without modifiers, with the addition of SBR latex and PP fiber into the rubber mortar, the flexural strength appeared a certain degree of increase by 5–30%, the compressive strength of specimens faced a significant reduction by 10–23%.

## 3. Effect of SBR Latex on Long-Term Deflection

Information on the creep characteristics of Latex Modified Concrete (LMC) is limited. A study by Ohama [6] showed that both the creep strain and creep coefficient of LMC are lower than those of unmodified concrete. His work also showed that the relationship between the time t, after the load is applied and creep strain fits the same general hyperbolic equation as that for unmodified concrete.[1]

Ghi & Eun [7] studied experimentally the time-dependent behavior of concrete using unsaturated polyester resin, it’s been concluded that the creep strains grow rather fast at early ages in comparison with ordinary concrete, because creep in polymer concrete results from molecular movement in the visco-elastic resin binder. The recycled-polymer concrete shows more than 20% of its long-term creep within the first two days, and about 50% during the first 20 days. Also, the creep strain of polymer concrete

without filler is much higher than that of polymer concrete with filler, because the filler plays an important role in restricting the deformation of polymer concrete.
Al-Kubaisy [8] studied the effect of SBR on the short and long term deflection of PMC slabs, (8) slabs were casted, (2) slabs for each one of the four SBR ratios were used (0%, 3%, 5%, and 7%). All panels are with dimensions 800×800×50 mm tested for about (6) months. Her work showed that increasing SBR ratio will reduce the long term deflection; also the result showed that increasing SBR ratio leads to reduce the long term deflection multiplier by about 13%.

## 4. Material and Experimental Program

### *4.1. Cement*

During the preparation of the mix, ordinary Portland Cement (OPC) provided by Tassluja Factory in Sulymaniyah, Iraq was used. The chemical composition of the cement is given in Table 1, and the physical properties are shown in Table 2.

Table 1. Chemical Compositions and Compounds of Portland Cement

| Oxide | % by Weight |
|---|---|
| CaO | 62.13 |
| MgO | 2.7 |
| SiO2 | 22.01 |
| SO3 | 2.4 |
| Fe2O3 | 3.3 |
| Al2O3 | 5.26 |
| Loss on ignition | 1.45 |
| C3S | 32.5 |
| C2S | 38.7 |
| C3A | 8.3 |
| C4AF | 10.4 |

Table 2. Physical Properties of Portland Cement

| Physical properties | Test result |
|---|---|
| Specific surface area (Blain) $cm^2/g$ | 290 |
| Initial setting (Vicat Method) min. | 92 |
| Final setting (Vicat Method) hr. | 3:30 |
| Compressive strength (MPa) | |
| 3-days | 16.5 |
| 7-days | 25.7 |

### *4.2. SBR Latex*

A milky-white fluid locally available by Sika- Synthetic Rubber Latex was used as SBR Latex to produce Latex-Modified Concrete (LMC).

### *4.3. Fine aggregate (sand)*

Natural sand brought from Gorashinregionwas used throughout this workwith maximum size of 4.75 mm. The grading of the sand was conformed to the Iraqi specification No. 45/1984 (9). Table 3 shows the sieve analysis of the fine aggregate used.

Table 3. Sieve Analysis of Fine Aggregate

| sieve No. | % Pass | Limits of Iraqi specification, No 45/1984 Zone 2 |
|---|---|---|
| 4.75 | 99.9 | 90-100 |
| 2.36 | 84.8 | 75 -100 |
| 1.18 | 72.2 | 55-90 |
| 0.6 | 34.6 | 35 -59 |
| 0.3 | 10.7 | 8-30 |
| 0.15 | 2.2 | 0-10 |
| 0.075 | 0.6 | <=5% |

### *4.4. Coarse aggregate*

Crushed gravel was used in this work. According to the recommendations of ACI 211.4R-93 [10] for mix selection of high performance concrete, maximum size of 10 mm (3/8 in) was selected. The crushed river gravel coarse aggregate were washed, then stored in air to dry the surface, then stored in containers in a saturated surface dry condition before using. Table 4 shows the sieve analysis of the coarse aggregate used.

Table 4. Sieve Analysis of Coarse Aggregate

| Sieve No. | % Pass | Limits of Iraqi specification, No 45/1984 Zone 2 |
|---|---|---|
| 12.5 | 100 | 35-70 |
| 9.5 | 96.5 | |
| 4.75 | 15.1 | 10-40 |
| 2.36 | 0.5 | |

### *4.5. Mixing water*

Tap water was used for casting and curing all the specimens.

### *4.6. Steel Reinforcing Bars*

Two sizes of steel bars were used, 10mm diam. for main bars, and 8 mm diam. for shear stirrups. Yield strength of the bars was determined by tensile test. Results of test showed that the yield strength of the bars equal to 420 MPa.

### *4.7. Specimen preparation*

Constant concrete mix ratios were used in the experimental programme, which are [(W+SBR)/CM] of ratio of 0.3, and P/CM ratios of (0%, 5%, 10%, and 15%) and Sand/CM ratio of 1.2, Gravel/CM ratio of 1.8 as shown in Table 5. First, water quantity calculated by subtracting SBR quantity from the needed volume. The SBR latex was added to the water and mixed well before using. Also, the quantity of cement needed prepared by subtraction the total cementitious material needed (500 $kg/m^3$) from the SBR quantity.

The beams' moulds and cubes of dimension 100mm were prepared, oiled, and casted. The specimens were demoulded after 24 hours and cured for 28 days immersed in room temperature water. Three cubes were casted for each beam specimen.

Table 5. Identification and Mix Ratios of the Tested Beams

| ID | C | P/C | (W+SBR)/CM | S/CM | G/CM |
|---|---|---|---|---|---|
| NCB-4 | 1 | 0 | 0.3 | 1.2 | 1.8 |
| PCB-3 | 0.95 | 0.05 | 0.3 | 1.2 | 1.8 |
| PCB-2 | 0.9 | 0.1 | 0.3 | 1.2 | 1.8 |
| PCB-1 | 0.85 | 0.15 | 0.3 | 1.2 | 1.8 |

Notes;
C = Cement, P = Polymer, W = Water, S = Sand, G = Gravel,CM = C+SBR,
Cementitious Content (CM) for all mixes was 500 $kg/m^3$
All ratios are per weight.

## 5. Test Specimens

### *5.1. Beams Specifications*

A total of 4 RC beams were tested in flexure. All beams were 150 mm in width and 150 mm in depth. The overall length of the beams was 750 mm, with a clear span of 680 mm as shown in Figure 1. The tensile reinforcement consisted of two bars of 10 mm diameter, and the compression reinforcement consisted of two bars of 10 mm diameter also. The shear-span was reinforced with steel stirrups (8mm diam @ 150mm spaces). The effective depth of the beams was 115 mm.

The identification and the geometric properties of the tested beams are summarized in Table 6.

Table 6. Identification and geometric properties of the tested beams

| ID | SBR % | Dimensions | | | Reinforcement | |
|---|---|---|---|---|---|---|
| | | b = h mm | d mm | L mm | As = As' $mm^2$ | ρ = ρ' |
| NCB-4 | 0 | 150 | 115 | 680 | 2ϕ10 = 157 | 0.009 |
| PCB-3 | 5 | 150 | 115 | 680 | 2ϕ10 = 157 | 0.009 |
| PCB-2 | 10 | 150 | 115 | 680 | 2ϕ10 = 157 | 0.009 |
| PCB-1 | 15 | 150 | 115 | 680 | 2ϕ10 = 157 | 0.009 |

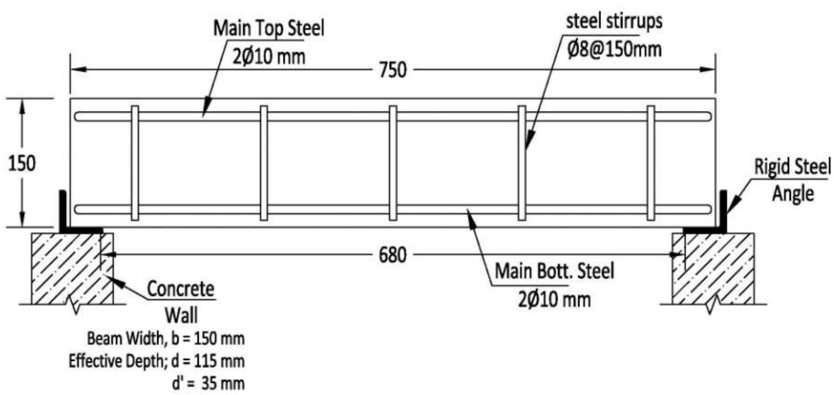


Figure 1. Dimensions and details of the experimental beams

### *5.2. Curing*

All beams and cubes are kept in a curing water tank for 28 days. After that, both were taken out of water, the cubes tested after one hour, and the beams installed on its place and loaded after 24 hours.

### *5.3. Test set-up*

The simply supported beams were subjected to a uniform distributed load of 2.3 kN/m including the weight of beam, as shown in Figure 2.

The experimental program consisted of measuring the deflection immediately after the load applied, after the short-term reads, the sustained loads kept for a period of 370 days. The sustained load, $W_{sus}$, was selected to obtain instantaneous concrete compressive stresses of (0.1 fc’) at the top and bottom fibers of the mid-span section. For beam identification, PCB-1 to PCB-3 corresponds to beams tested with polymer ratios of 15%, 10%, and 5% respectively, while NCB-4 is used for the unmodified concrete reference beam (i.e. without polymer content).

For each beam, one dial gauge (of 0.01 mm accuracy) was used to measure the deflection at mid-span.

Figure 2. Illustration of beams during testing

## 6. Results and Discussion

### *A. Unit Weight (Density)*

Unit weight (or density) of the hardened concrete been measured at 28 days. The test results of the density for the HPC with different polymers at 28 days are shown in Figure 3. For the SBR modified concrete, the density slightly increased with increasing the SBR contents, such that, the density increase 3.2% when the SBR ratio increased from zero to 15%, with an average density of 2415 kg/m$^3$ for reference concrete, and 2480 kg/m$^3$ for polymer concrete.

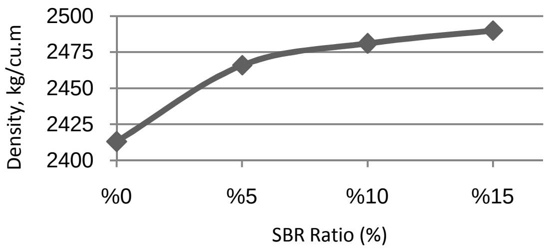


Figure 3. Densities with different contents of polymers at 28 days

### *B. Compressive strength*

In general, PMC has lower compressive strengths than unmodified concretes with similar cement, aggregate, and water contents [1]. Cubes of size 100 mm was used, the compressive strength of SBR latex-modified concretes with a different P/C ratio were recorded. It shows that the compressive strength decreases with the increasing of P/C ratio; such that the decrease was about 30% when Latex increased from 0% to 15% as shown in Figure 4.

The decrease in the compressive strength with increasing polymer content is due to lower density of latex with regards to matrix density (mix rheology) [4] and also explained by the constant W/CM ratio considered in the experimental programme leads to reducing cement content with the increasing of SBR ratio to keep the same cementitious (CM) amount for all beams

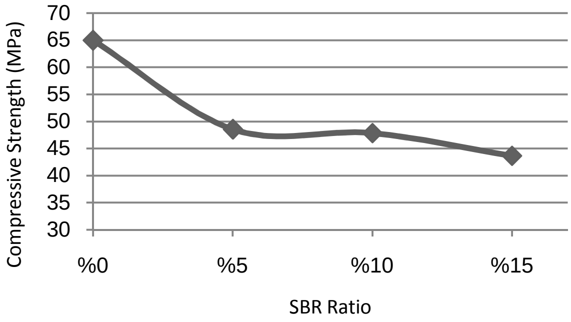


Figure 4. Compressive Strength with SBR Content Relationship

### *C. Short Term Deflection*

The deflections of beams recorded immediately after the beams are loaded in place on their supports. Table 7 summarizes the tested beams, giving actual compressive strength of concrete, and measured short-term deflections. The instantaneous deflections are measured for all beams at an age of 28 days [8, 12]. The age of concrete beams when loaded was 1 day after curing finish for all beams.

Table 7. Measured Short-Term Deflection

| Beam No. | P/C | fcu )28 MPa | fc′ )28 MPa(13) | Measured $(\Delta s)$mid. $(mm\times10^{-2})$ |
|---|---|---|---|---|
| NCB-4 | 0 | 64.93 | 55.19 | 5.6 |
| PCB-3 | 5% | 48.51 | 41.24 | 6.6 |
| PCB-2 | 10% | 47.83 | 40.65 | 7.6 |
| NCB-1 | 15% | 43.65 | 37.10 | 9.1 |

Plots of the measured mid-span short deflection versus SBR ratio for four beams are shown in Figure 5, it can be seen that the increase in SBR ratio increase the short-term deflections because the concrete strength decreased and hence modulus of elasticity.

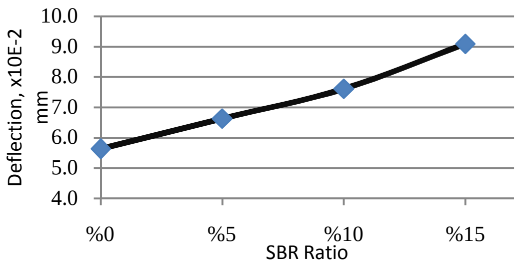


Figure 5. Measured mid-span short deflection

### *E. Long Term Deflection*

Ohama (1995) [6] stated that there are conflicting data exist on the creep behavior of latex-modified concrete. The creep characteristics of SBR-modified concretes which reported by himself (14) is like ordinary cement concrete, the relationships between loading time (t) and creep strain or creep coefficient (i.e., creep strain/elastic strain ratio) of the latex-modified concretes are considerably lower than those of unmodified concrete. The latex-modified mortars and concretes generally exhibit small creep in spite of the inclusion of flexible polymers with low glass transition temperatures. This may be related to the lower polymer content of about 3 vol%, the strengthening of binder with polymers, and the long-term strength development with improved water retention.

By contrast**,** Solomatov [15]found that the creep deformation in flexure of poly(vinyl acetate-dibutyl maleate)-modified mortar was several times larger than that of unmodified concrete at 20°C, and its catastrophic deformation occurred at 50°C since the polymer developed a high plasticity above its glass transition temperature.

In this work, beams were loaded for a long period to evaluate the time-dependent deflection behaviour. Deflection measurements were taken over a 370 days period under the predetermined level of sustained load to permit assessment of this effect.

Plots of the measured mid-span deflection versus time for the four beams are shown in Figure 6, it can be seen that the deflection increases with time due to the effects of creep and shrinkage. However, the rate of increase of deflection decreases with time.
A large increase in deflection is noticed during the first three months after the load is applied. After that, the rate of increase became smaller as time progressed, i.e., in all beams there is a substantial increase of deflection followed by a period where the deflection increases are minimal. Table 8 summarizes the measured long-term deflections multiplier for each loaded beam. It can be seen that the rate of increase in LMC beams' long time deflection is less than that of unmodified concrete beams.

The ratio of deflection increments between the 28-days and more than 1-year periods for LMC beams was less than the unmodified concrete beam by 20% in average. Tests also showed that when 15% SBR added, minimum long-term deflection multiplier is recorded, but when the ratio decreased, the long-term deflection multiplier increased because both creep strain and creep coefficients of LMC concretes are considerably lower than those of unmodified concrete [6].

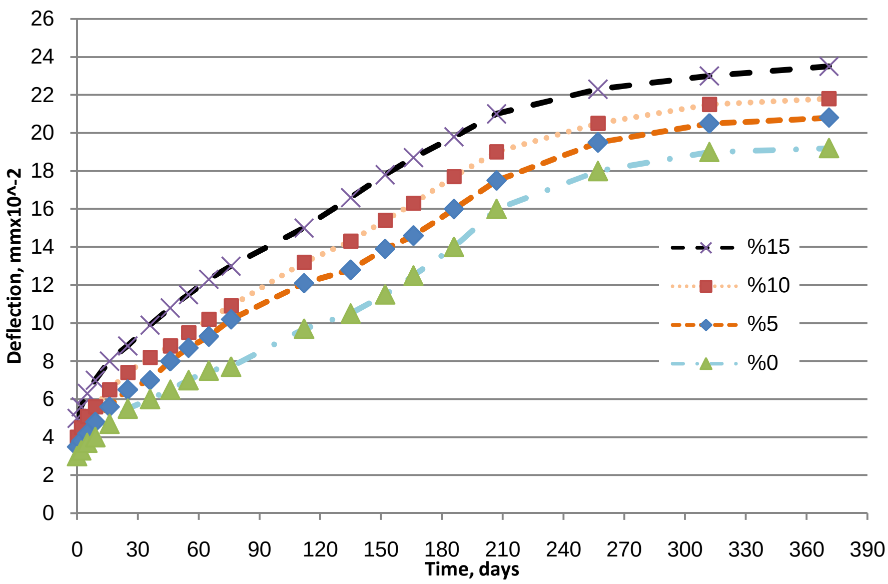


Figure 6. Measured mid-span deflection versus time for all beams

Table 8. Ratios of Long-Term over Short-Term Deflections (ΔL/ΔS) for all Beams

| SBR Ratio / Time days | 0% | 5% | 10% | 15% |
|---|---|---|---|---|
| 28 | 1 | 1 | 1 | 1 |
| 40 | 1.10 | 1.12 | 1.11 | 1.13 |
| 60 | 1.29 | 1.36 | 1.29 | 1.31 |
| 80 | 1.41 | 1.57 | 1.46 | 1.45 |
| 100 | 1.60 | 1.73 | 1.63 | 1.58 |
| 120 | 1.77 | 1.86 | 1.78 | 1.71 |
| 140 | 1.92 | 1.98 | 1.92 | 1.86 |
| 160 | 2.14 | 2.15 | 2.09 | 2.01 |
| 180 | 2.40 | 2.35 | 2.27 | 2.14 |
| 200 | 2.72 | 2.56 | 2.44 | 2.26 |
| 220 | 2.93 | 2.72 | 2.55 | 2.34 |
| 240 | 3.07 | 2.84 | 2.62 | 2.40 |
| 260 | 3.20 | 2.95 | 2.70 | 2.45 |
| 280 | 3.27 | 3.00 | 2.75 | 2.48 |
| 300 | 3.33 | 3.06 | 2.79 | 2.51 |
| 320 | 3.38 | 3.10 | 2.83 | 2.53 |
| 340 | 3.39 | 3.11 | 2.84 | 2.55 |
| 360 | 3.40 | 3.13 | 2.85 | 2.57 |
| 370 | 3.41 | 3.13 | 2.86 | 2.58 |

Table 9 shows the short-term deflection and the experimental long-term deflection increment, and Figure 7 shows the long-term deflection multiplier, at the end of test.

Table 9. Test Results of Sustained Loading

| Beam No. | P/C | short term deflection Δs ($\times 10^{-2}$mm) | Exp Def. increment Δi ($\times 10^{-2}$mm) |
|---|---|---|---|
| NCB-4 | 0% | 5.6 | 13.56 |
| PCB-3 | 5% | 6.6 | 14.16 |
| PCB-2 | 10% | 7.6 | 14.18 |
| PCB-1 | 15% | 9.1 | 14.40 |

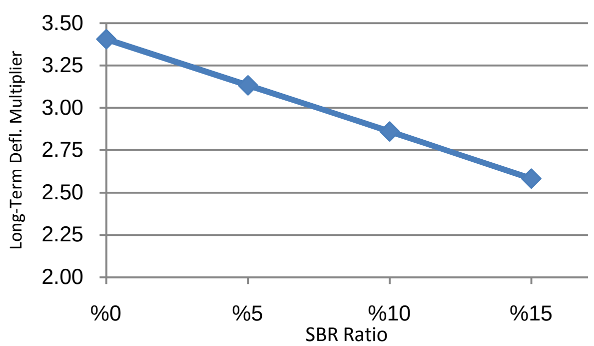


Figure 7. Measured long-term deflection multiplier for all beams

## 7. Conclusions

In the following, conclusions are drawn regarding this work;

1. Density of concrete increased about 3% with the increasing of SBR ratio from zero to 15%,due to the reduction in W/C ratio, the increase in compaction, and reduce concrete porosity. The polymer latex addition into fresh concrete causes the effect almost typical to that of admixtures like superplasrisizer which leads to better workability results that are known as ball-bearing influence of surface active substance inpolymer latex.[16]
2. Compared to the unmodified concrete, with the addition of SBR latex into the mix, the compressive strength of specimens faced a considerable reduction by 25–32% when SBR Latex ratio increased from 5 to 15%.
3. The tests showed that adding SBR to the concrete will enhance the long term behaviour.
4. The overall trend of deflection-time curves are similar. The LMC beams showed little more value at $1^{st}$ week and clearly more values at later days.
5. The 370-days centre beam deflection for control beam was (0.192) mm, while it was (0.208, 0.218, and 0.235) mm for LMC beams for SBR ratios (5%, 10%, and 15%) respectively. Ratio of $\Delta_{LMC}$ / $\Delta_{control}$ are (1.08, 1.14, and 1.22).
6. Although the long-term deflection of LMC is more than the unmodified concrete, but the multiplier was less than the unmodified ones, indicating an overall better performance of LMC concrete beams in long-term deflection.
7. The 370-days ratio of long term to short-term deflection ($\Delta_L/\Delta_S$) for control panel was (3.41), the corresponding ratios for LMC panels are (3.13, 2.86 and 2.58) for SBR ratios (5%, 10%, and 15%) respectively. The values of ACI ratio (2.0) for beams seems doesn't fit. A value of 2.5 as suggested by Branson [17] sound more suitable for HS LMC concrete beams.
8. About 75% increase in deflection was noticed during the first six months after the load is applied. At the last three months, the rate of increase became smaller as time progressed and it was about 7% from total deflection increment.
9. The rate of increase in deflection of unmodified concrete was about 10% more than LMC in first 6 months.

### Abbreviations

| | |
|---|---|
| HSC | : High Strength Concrete |
| NSC | : Normal Strength Concrete |
| W/C | : Water / Cement Ratio |
| CM | : CementitiousMaterials (C+SBR) |
| $f_{cu}$ | : Cube Concrete Compressive Strength |
| fc' | : Cylinder Concrete Compressive Strength |
| $\Delta_S$ | : Short Term Deflection |
| $\Delta_L$ | : Long Term Deflection |
| $\Delta_i$ | : Long Term Deflection Increment |
| HPC | : High Performance Concrete |

SBR : Styrene-Butadiene-Rubber
PAE : PohrawlicFster, Thermoplastic Latexes
PMC : Polymer-Modified Concrete
OPC : Ordinary Portland Cement
LMC : Latex-Modified Concrete

## 8. References


1. ACI 548.3R-03, *Polymer-Modified Concrete*, Reported by ACI Committee 548, 2003.
2. YahyaM. ,Binsheng Zhang, BarkerM. (2014). "*Influence of Styrene-Butadiene-Rubber latex (SBR) and Polyvinylidene Chloride (PVDC) on mechanical properties of HPC",* Conference: The 2014 World Congress on Advances in Civil, Environmental, and Materials Research (ACEM14), Busan, Korea, pp 24-28.
3. Al-Nu'manB.S. and Al-Hadithi A.I. (2009)."*Flexural Behaviour of Polymer Modified Reinforced Concrete Beams*", Journal of Engineering and Development, Vol. 13, No. 1, ISSN 1813-7822.
4. MelkundiM.V., Prof. HalhalliV. (2013)."*Experimental Investigation of SBR-Latex modified Steel Fiber Reinforced Concrete*", International Journal of Engineering Research & Technology (IJERT), Vol. 2, Issue 11,ISSN: 2278-0181.
5. Fang Xu, Jianping Chen, ShaoqinRuan, Mingkai Zhou. (2014)."*Influence of PP Fiber and SBR Latex on the Mechanical Properties of Crumb Rubber Mortar*", Journal of Appl. Polymer. SCI. 2014, DOI: 10.1002/APP.40591, Wiley Periodicals, Inc.
6. OhamaY. (1995)."*Handbook of Polymer-Modified Concrete and Mortars, Properties and Process Technology*", NOYES PUBLICATIONS, Park Ridge, New Jersey, U.S.A.
7. Ghi Ho Tae and EunSoo Choi. (2012). "*Time Dependent Behaviour of Polymer Concrete Using Unsaturated Polyester Resin*", http://dx.doi.org/10.5772/47181, open access chapter distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0).
8. Al-Kubaisy H.K. (2004). "*Short and Long-Term Deflections of Reinforced Polymer Modified Concrete Panels*", M.Sc. Thesis, College of Engineering, Al-Mustansiriyah University, Baghdad, Iraq.
9. Iraqi Specifications No. (45), 1984 for Aggregates of Natural Resources used for Concrete and Construction.
10. ACI 211.4R-93. (1994).*"Guide for Selecting Proportions for High-Strength Concrete With Portland Cement and Fly Ash"*, ACI Manual of Cement Practice, Part 1: Materials and General properties of concrete, pp.13, Detroit, Michigan.
11. Ohama, Y., and Hashimoto, H., "*Drying Shrinkage and Compressive Creep of Polymer-Modified Concrete (in Japanese)*", Semento-Gijutsu-Nempo 32, Dec. 1978, pp. 308-311. *(Seen by Ref. No. 11).*
12. Figarovskij, V. V. (1962). "*Experimental Investigation of Stiffness and Cracking of Reinforced Concrete Flexural Members Subjected to Short-Term and Long-Term Loading*", Ph.D. Thesis (in Russian), Moscow.

13. Neville, A. M. "*Properties of Concrete*" Pitman publishing Limited, London's 4th Edition 2000, pp. 674-760.
14. Ohama, Y., and Hashimoto, H., "*Drying Shrinkage and Compressive Creep of Polymer-Modified Concrete (in Japanese)*", Semento-Gijutsu-Nempo 32, Dec. 1978, pp. 308-311. *(Cited by Ref. No. 6).*
15. Solomatov, V. I. (1967). "*PolimerTsementnye Betony in Plastbetony*", pp. 4246, Izdatel'stvoLiteraturypoStroitel'stvu, Moscow. *(Cited by Ref. No. 6).*
16. Mebarkia, S.; Vipulanandan, C. (1995). "*Mechanical Properties and Water Diffusion in Polyester Polymer Concrete*", Journal of Engineering Mechanics, ASCE. Vol. 121, No. 12, pp. 1359-1365.
17. Branson D.E. (1977). "*Deformation of Concrete Structures*", McGraw-Hill Book Company, 546 pp.