Effect of Styrene Butadiene Rubber Latex on Mechanical Properties of Eco Concrete: Limestone Powder Concrete

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***Abstract*–To make concrete a truly green material, viable cement substitutes are available. This experimental investigation is performed to study the effect of using limestone powder (LSP) and styrene butadiene rubber (SBR) latex in the concrete mix. In this work, a concrete with 1:1.8:3 cementitious material:sand:gravel and water/cement ratio w/c of 0.5 is produced. First, LSP is used with 0, 5, 10, 15, and 20% replacements by weight of cements. The fineness of the LSP is measured using sieve No. 200 and showed about 30% pass. Second, and to improve the matrix of concrete due to the dilution effect, four ratios of SBR latex (0, 5, 10, and 15%) are added by weight of cements to the mix for each LSP ratio. Compressive strength at ages of 3, 7, 14, 28, and 90 days is tested for the concrete specimens mixed with LSP only to examine its effect on concrete strength's development with time, whereas strengths are recorded at the age of 28 days for the other concretes. Three prisms were cast for each ratio and tested at 28 days. The results show general improvements in terms of compressive and flexural strengths.**

***Index Terms*–Compressive strength, Flexural strength, Limestone filler, Portland cement, Styrene butadiene rubber latex.**

I. Introduction

It has been proved that every ton of cement produced leads to about 0.9 ton of CO_2 emissions and a typical cubic meter of concrete contains about 10% by weight of cement, that leads to about quarter tons of CO_2 (Obla, 2009). Many studies have been written about reducing the CO_2 emissions from concrete primarily through the reduction of amounts of cement used in concrete and replacing it with supplementary cementitious material (CM) such as limestone powder (LSP), fly ash, polymers, nano-*silica*, and slag.

LSP and styrene butadiene rubber (SBR) latex have been used widely with many effects on the cement properties due to its action as a filler or binder between the concrete particles and producing a denser paste and densifying the interfacial zone between the aggregate and cement paste.

II. Previous Works on LSP Concrete

The performance of LSP filler addition to Portland cement has been studied in pastes, mortars, and concretes. In general, limestone filler improves the hydration rate of cement compounds and consequently increases the strength at early ages. Tarun, et al., 2003, states that LSP filler in concrete leads to dilution of cement, high effective w/c ratio, and increases the strength at early ages. The use of LSP in concrete provides environmental and economic advantages by reducing Portland cement production and hence CO_2 emission, as well as improving the early and the later age compressive strength.

Ahmed, et al., 2009, discussed the effect of increasing temperature, when part of cement is replaced by LSP, on the compressive and tensile strength of concrete. Several LSP ratios were used (0, 10, 15, 20, and 25%) as compensating material. The temperature elevated to 200, 400, and 600°C. It has been concluded that when LSP ratio exceeds 15%, both compressive and tensile strength is reduced, and when exposed to high temperature, severe drop in concrete strengths occurs in different forms.

Thongsanitgarn, et al., 2011 studied the behavior of Portland cement paste when part of cement is replaced by LSP with percentages of 0, 5, 7.5, 10, 12.5, 15 and 20% by weight with three degrees of fineness for each percentage. The study covered the effect of LSP on the compressive strength and setting time of concrete. It has been concluded that replacing cement by LSP caused reduction in compressive strength and increasing the fineness of LSP will increase it but it would require more water. Both initial and final setting times were decreased with the increase of the LSP amount.

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III. Previous Works on Polymer Modified Concrete

The use of SBR emulsions in concrete has been increasing in concrete construction and repair work due to its benefits to flexure strength, adhesion, and impermeability.

Essa, et al., 2102, studied the effect of adding SBR on both cement paste and concrete. Several ratios chosen from 10% to 35% by volume of water were used to study the early and late strength of concrete. It has been concluded that adding SBR has a considerable negative effect on the early strength of concrete, but it has a positive effect for later ages. In addition, it showed an increase in compressive strength with increasing the added dosage of SBR. Furthermore, adding of SBR to concrete mix caused an increase in flexural strength at 28 days by 7%, 33%, and 53% for SBR dosage of 10%, 25%, and 35%, respectively.

Yao and Ge, 2012, evaluated the influence of different contents (0, 5, 10, 15, and 20% by cement) of SBR on the mechanical properties of concrete with the same w/c ratio. The compressive strength, flexure strength, permeability, and elastic modulus were studied. Experimental results showed that the compressive strength, elastic modulus, and permeability were decreased when SBR latex ratio increased while the flexural strength increased.

IV. Material and Experimental Program

A. Cement

During the preparation of the mix, ordinary Portland cement (OPC) provided by Tassluja factory in Sulaymaniyah, Iraq, was used. The chemical composition and the physical properties of the cement are illustrated in Table I and it is conforming to the Iraqi specification IQS No. 5-1984.

B. SBR Latex

A milky-white fluid locally available by Sika-Synthetic Rubber Latex, as shown in Fig. 1, was used as SBR latex to produce latex-modified concrete. Table II presents that the SBR used complies with ASTM C1042 and C1059-99, Type I, redispersable bonding admixture.

Fig. 1. Styrene butadiene rubber used in the present work.

C. Fine Aggregate (Sand)

Natural sand is used throughout this work with the maximum size of 4.75 mm. The grading of the sand was conformed to the Iraqi specification No. 45/1984. Table III presents the sieve analysis of the fine aggregate used.

D. Coarse Aggregate

Natural river gravel with irregular shape is used with a maximum size of 12.5 mm for all mixes. The gravel was

TABLE I
Chemical Compositions and Physical Properties of Portland Cement

Oxide		% by weight	IQS 5:1984 limits
Lime	CaO	62.13	-
Magnesia	MgO	2.24	≤5
Silica	SiO_2	22.1	-
Sulfate	SO_3	1.07	≤2.5 if C3A <5% ≤2.8 if C3A >5%
Iron oxide	Fe_2O_3	3.53	-
Alumina	Al_2O_3	5.49	-
Loss on ignition	LOI	1.45	≤4
Insoluble residue	IR	0.32	≤1.5
Lime saturation factor	LSF	0.86	0.66-1.02
Main compounds (Bogue's equation)			
Tricalcium silicate	C3S	38.55	
Dicalcium silicate	C2S	33.15	
Tricalcium aluminate	C3A	8.58	
Tetracalcium aluminoferrite	C4AF	10.73	
Physical properties		Test result	
Specific surface area (blain) cm^2/g		310	≥250
Soundness using autoclave method		0.19%	≤0.8
Initial setting (Vicat method) min		165	≥45
Final setting (Vicat method) h		04:05	≤10
Compressive strength (MPa)			
3 days		16.5	≥15
7 days		25.7	≥23

LOI: Loss on ignition, IR: Insoluble residue, LSF: Lime saturation factor

TABLE II
SBR Latex Used in this Study

Physical properties	Test result	ASTM limits
Density	Approx. 1 kg/L	
Solid content	Approx. 47%	
pH value	Approx. 10	
Compressive strength		
7 days	35 MPa	
28 days	45 MPa	≥31
Tensile strength		
7 days	3.5 MPa	
28 days	3.7 MPa	
Bond strength		
7 days	2.5 MPa	
28 days	3.0 MPa	≥2.8
Flexural strength		
7 days	6.0 MPa	
28 days	7.0 MPa	
Shrinkage (28 days)	Approx. <500 μm/m	
Elastic modulus (28 days)	Approx. 15 kN/mm^2	

washed, then stored in air to dry the surface, and then stored in containers in a saturated surface dry condition before using. Table IV shows the sieve analysis of the coarse aggregate used.

E. Mixing Water

Throughout the investigation, tap water supplied for drinking consumption was used for concrete mixing and curing the hardened concrete samples.

F. Limestone Filler

Limestone used consists essentially of calcium carbonate and generally with some magnesium carbonate and siliceous matter such as quartz grains. The limestone may be composed of four minerals: Calcite ($CaCO_3$), aragonite, dolomite ($CaMg(CO_3)_2$), and magnesite ($MgCO_3$) (Noori, 2016). Table V presents the specifications of LSP and it is conforming to the ASTM C150 standard.

G. Mix Preparation

The work was divided into two series; the first one is to study the effect of LSP on concrete physical properties (Table VI), whereas the second is to study the effect of adding SBR latex to the concrete containing LSP (Table VII). For both series, constant concrete mix ratios were used in the experimental program, which are (W+SBR)/CM ratio of 0.5, and varying ratios of LSP/CM ratios of 0%, 5%, 10%, 15, and 20%, SBR/CM (0%, 5%, 10%, and 15%) with S/CM ratio of 1.8, and G/CM ratio of 3 as shown in Tables VI and VII.

First, LSP quantity was weighed, then water quantity was calculated by subtracting SBR quantity from the needed volume. The LSP was added to the mix with cement before adding the water, whereas the SBR latex was added to the water and mixed well before using. The quantity of cement needed was measured by subtracting the LSP quantity from total CM needed (350 kg/m^3).

The cubes and prisms molds were prepared, oiled, and cast. Then, specimens were demolded after 24 h and cured in room temperature water. Three cubes and three prisms were cast for each ratio except for the 0% SBR, for which 15^3 were cast to be tested at 3, 7, 14, 28, and 90 days to examine the LSP effect on early and longtime stages.

TABLE III
Sieve Analysis of Fine Aggregate

Sieve opening (mm)	% 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%

TABLE IV
Sieve Analysis of Coarse Aggregate

Sieve opening (mm)	% 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	

TABLE V
Chemical Compositions and Physical Properties of Lsp

Mat	Percentage	ASTM C150 limits
CaO	52.60	
MgO	1.446	≤6
SiO_2	2.701	
SO_3	0.170	≤3.0
Fe_2O_3	0.395	
Al_2O_3	1.196	
P_2O_5	0.035	≤0.1
Na_2O	0.042	
K_2O	0.070	
MnO	0.005	
$CaCo_3$	93.94	

H. Samples Specifications

A total of 111 cubes were tested in compression and 51 prisms in flexure were designed to study all parameters in addition to the control mix made without limestone fines or SBR. Limestone fines were added in different percentages ranging from 0.0% to 20%, whereas SBR was ranging from 0.0% to 15% and both with 5% increments. All cubes were 100 mm in dimensions and all prisms were of size 100 mm × 100 mm × 450 mm with tested span of 400 mm.

I. Curing

All prisms and cubes are kept in a curing water tank to the test day, and then, they were taken out of water and tested after 1 h (Fig. 2).

J. Test Set-up

All the cubes were tested using standard testing machine (AUTOMAX5 made by CONTROL Group, as shown in Fig. 3a) with a capacity of 2000 kN. The test was conducted at ages of 3, 7, 14, 28, and 90 days. Each result of compressive strength obtained is the average for three specimens. The load was applied at a rate of 0.8 MPa/min.

Fig. 2. Some of cubes and prisms during curing.

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Flexural strength test was done by third-point loading method as shown in Fig. 3(c). Prisms were tested for flexure in universal testing machine of capacity 100 kN (using ALPHA machine, as shown in Fig. 3b). The bearing surfaces of the supporting and loading rollers were wiped clean before loading. The prisms were placed in the machine in such a manner that the load was applied to the bottommost surface along the two lines spaced 40 cm apart. The axis of the specimen was aligned with the axis of the loading device. The load was applied at a rate of 2 mm/min. The specimen was loaded till it fails and the maximum load (P) applied to the specimen during test was recorded.

V. Experimental Results and Discussion

A. Compressive Strength

Series 1

Compressive strength measurements were carried out at ages of 3, 7, 14, 28, and 90 days. The compressive strength of LSP concrete was calculated from the average of three specimens and plotted as a function of limestone content. Fig. 4 shows the compressive strength of LSP concrete with time. The compressive strength is obviously related to the limestone content. It is found that the compressive strength of all LSP concrete specimens is lower than those of OPC control and decreased with increasing limestone content.

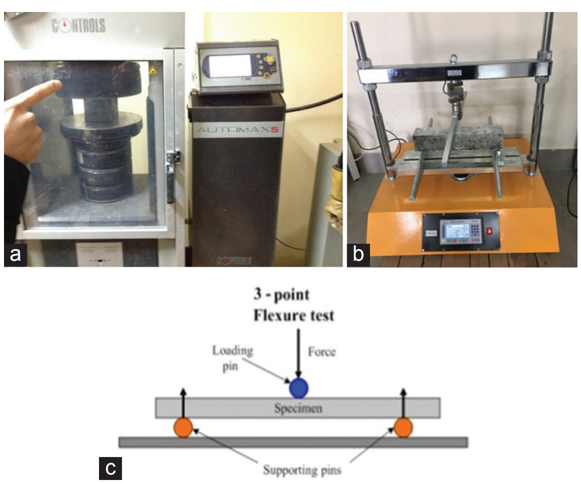

Fig. 3. Compression and flexural testing machines. (a) Testing compression machine, (b) testing flexural machine, (c) flexural test illustration.

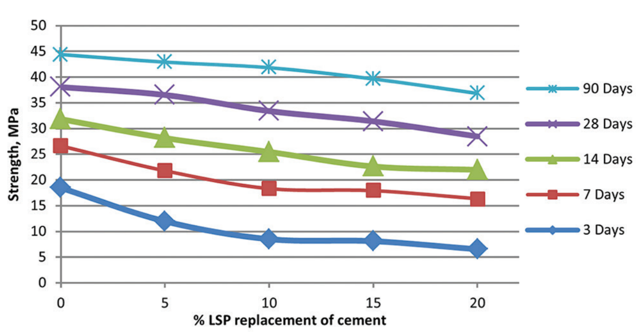

Fig. 4. Concrete compressive strength with limestone powder content.

The replacement of Portland cement by LSP caused a reduction in the compressive strength that can be explained as a result of cement dilution effect. It is indicated that the filler effect cannot compensate for the dilution effect at all ages. It was also found that all LSP concrete specimens show an increase in compressive strength with increasing curing time. Fig. 5 shows the compressive strength of LSP concrete at 3, 7, 14, 28, and 90 days of curing.

It has been found that addition of LSP into concrete improves the late strength such that the ratio of fc90 days/

TABLE VI
Identification and Mix Proportions of Series I

No.	ID	LSP (%)	CM	(W+SBR)/CM	C	S/CM	G/CM
1	L00P00	0	1.0	0.5	1	1.8	3
2	L05P00	5	1.0	0.5	0.95	1.8	3
3	L10P00	10	1.0	0.5	0.9	1.8	3
4	L15P0.0	15	1.0	0.5	0.85	1.8	3
5	L20P00	20	1.0	0.5	0.8	1.8	3

C: Cement, P: SBR: Styrene butadiene rubber, W: Water, S: Sand, G: Gravel, LSP: Limestone powder, CM: C+LSP, Cementitious material content (CM) for all mixes was 350 kg/m^3 all ratios are per weight for each line, 15 cubes and 3 prisms were cast.

TABLE VII.
Identification and Mix Proportions of Series II

No	ID	LSP (%)	SBR (%)	CM	(W+SBR)/CM	C	S/CM	G/CM
1	L00P00	0	0	1.0	0.5	1	1.8	3
2	L00P05		5	1.0	0.5	1	1.8	3
3	L00P10		10	1.0	0.5	1	1.8	3
4	L00P15		15	1.0	0.5	1	1.8	3
5	L05P00	5	0	1.0	0.5	0.95	1.8	3
6	L05P05		5	1.0	0.5	0.95	1.8	3
7	L05P10		10	1.0	0.5	0.95	1.8	3
8	L05P15		15	1.0	0.5	0.95	1.8	3
9	L10P00	10	0	1.0	0.5	0.9	1.8	3
10	L10P05		5	1.0	0.5	0.9	1.8	3
11	L10P10		10	1.0	0.5	0.9	1.8	3
12	L10P15		15	1.0	0.5	0.9	1.8	3
13	L15P0.0	15	0	1.0	0.5	0.85	1.8	3
14	L15P05		5	1.0	0.5	0.85	1.8	3
15	L15P10		10	1.0	0.5	0.85	1.8	3
16	L15P15		15	1.0	0.5	0.85	1.8	3

Cementitious material content (CM) for all mixes was 350 kg/m^3 LSP is a cement replacement ratio, whereas SBR is a water replacement ratio for each line, 3 cubes and 3 prisms were casted. LSP: Limestone powder, CM: Cementitious material, SBR: Styrene butadiene rubber

TABLE VIII
Concrete Compressive Strength (MPA) Variation With Lsp and Sbr Contents of Series II

Lime	SBR			
	P00	P05	P10	P15
L00	38.06	35.03	32.32	30.26
L05	36.54	32.21	30.42	27.02
L10	33.41	30.44	27.01	25.24
L15	31.41	28.00	25.29	22.56

LSP: Limestone powder, SBR: Styrene butadiene rubber fc28 days was 1.17 for the OPC, whereas it was 1.20, 1.25, 1.27, and 1.30 for LSP ratios of 5, 10, 15, and 20%, respectively. In other words, and as shown in Fig. 4, the drop in strength for late ages is less than the ones for early ages.

Series II

Compressive strength measurements at the age of 28 days are listed in Table VIII. The compressive strength of LSP concrete was calculated from the average of three specimens and plotted as a function of SBR content in Fig. 6 and plotted as a function of LSP content in Fig. 7.

As in Series I, the compressive strength is found to be decreased when SBR content increased. It has been found that addition of SBR into concrete by 5, 10, and 15% will slightly reduce the compressive strength by 10, 17, and 25% in average for LSP content, respectively, as shown in Fig. 6. It is worth to mention that these results are consistent with other works, like Yao and Ge, 2012; Wang, et al., 2005; Abd Elkam and Abd Elmoaty, 2012 on their polymer modified concrete work.

B. Flexural strength

Series 1

For evaluating the flexural strength, beam specimens of dimensions 100 mm × 100 mm × 450 mm were prepared. For testing, simple beam with third-point test was adopted on an effective span of 400 mm as per ASTM C 78-02. The test results are plotted in Fig. 8. It is seen that the 28-day flexural strength decreased up to 16% with LSP replacement of cement by 20% as shown.

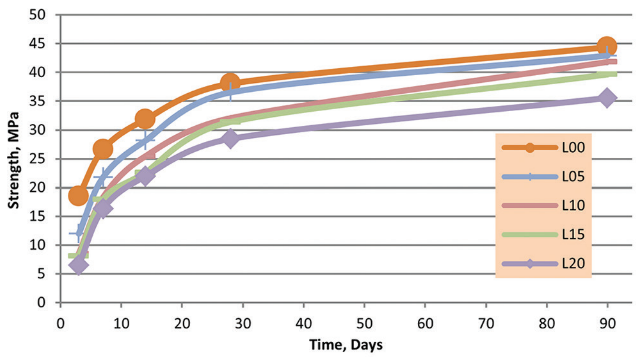

Fig. 5. Compressive strength of limestone powder concrete with time.

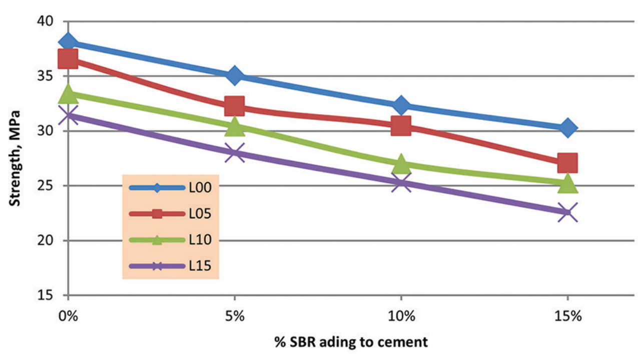

Fig. 6. 28-day compressive strength versus styrene butadiene rubber ratio of limestone powder concrete.

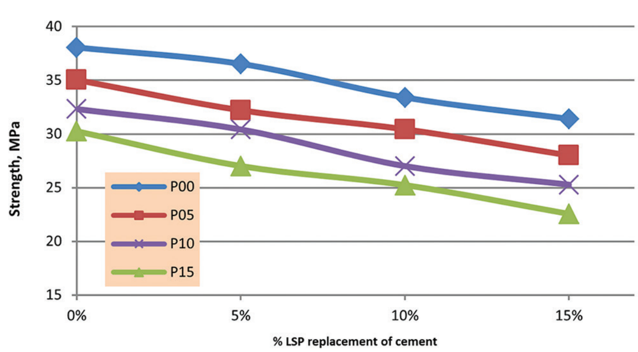

Fig. 7. 28-day compressive strength versus limestone powder ratio of polymer modified concrete.

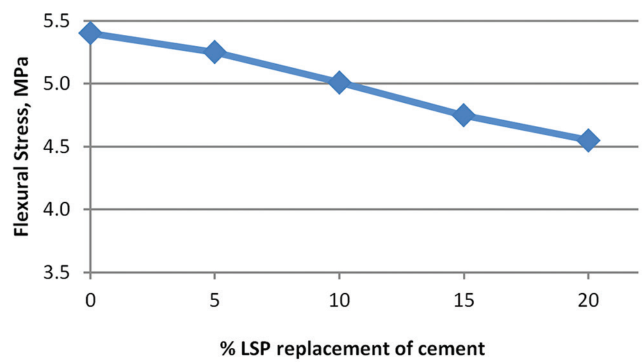

Fig. 8. Flexural strength of 28 days versus limestone powder content.

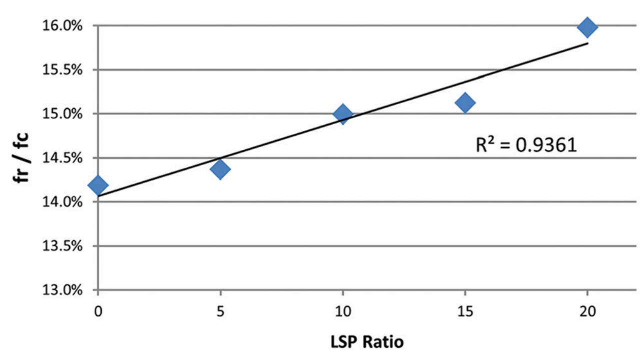

Fig. 9. Ratio fc'/fr versus limestone powder content at 28 days age.

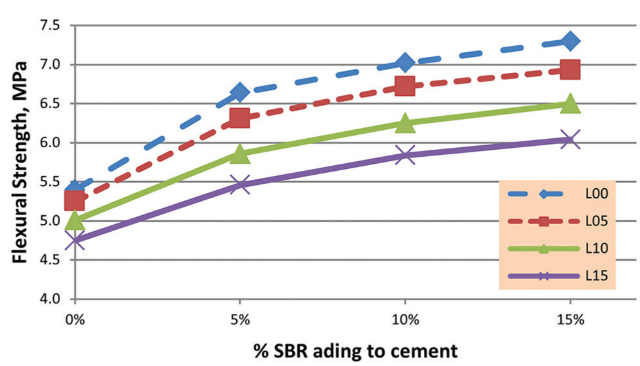

Fig. 10. Influence of styrene butadiene rubber latex on the flexural strength of concrete.

TABLE IX
CONCRETE FLEXURAL STRENGTH (MPA) VARIATION WITH LSP AND SBR CONTENTS OF SERIES II

Lime	SBR			
	P00	P05	P10	P15
L00	5.40	6.64	7.02	7.30
L05	5.25	6.31	6.72	6.93
L10	5.01	5.86	6.25	6.50
L15	4.75	5.46	5.84	6.04

LSP: Limestone powder, SBR: Styrene butadiene rubber

Furthermore, when increasing LSP content, the ratio of flexural tensile strength to compressive strength (fr/fc) increased from 14.2% to about 16%, as shown in Fig. 9.

Series II

Table IX and Fig. 10 illustrate the effect of SBR content on the flexural strength of concrete. The results showed that the flexural strength of the concrete increased when the SBR content increased. In general, adding 5, 10, and 15% of SBR increased the flexural strength by 23, 30, and 35% for zero LSP content. This ratio decreased when LSP content increased and become 15, 23, and 27% for 15% LSP content.

This improvement in flexural behavior happened because the SBR enhances the bonding of the interface between Portland cement paste and aggregate.

For the fr/fc ratio, it is increased from 15% to 26% in general with insignificant effect toward the LSP content.

VI. CONCLUSIONS

Several conclusions have been recorded in this study for adding LSP or SBR into the concrete mix. The following conclusions can be drawn from the obtained experimental data:

1. Strength development of LSP concrete is either similar to or little slower than that of normal concrete. The ratio of 7/28 days was about 60% in average for LSP concrete and 70% for normal concrete.
2. Using LSP has reduced the 28 days cubes concrete strength by about 4, 12, 17, and 25% when replacing cement by 5, 10, 15, and 20%, respectively.
3. Further to point (2), the compressive strength (from 7 to 90 days) of LSP concrete was decreased with the increasing amount of limestone due to the dilution effect.
4. Using LSP has reduced the 28 days flexural strength by about 4, 8, 12, and 16% when replacing cement by 5, 10, 15, and 20%, respectively.
5. Using SBR latex has reduced the 28 days compressive strength by about 10, 17, and 25% when adding SBR latex by 5, 10, and 15%, respectively, in average for all LSP content.
6. Using SBR latex has increased the 28 days flexural strength by about 19, 27, and 31% when adding SBR by 5, 10, and 15%, respectively.

REFERENCES

Abd Elkam, A.A., Abd Elmoaty, A.E., 2012. Experimental investigation on the properties of polymer modified SCC, Jr. *Construction and Building Materials*, 34, pp.584-592.

Ahmed, A., Abdurrahman, A. and Mohammed, Z., 2009 Influence of limestone powder as partial replacement of cement on concrete and the effect of high temperature on it, IASJ. *Al-Rafidain Engineering Journa*l, 18(5), pp.24-34.

ASTM C1042-99, 1999. *Standard Test Method for Bond Strength of Latex Systems used with Concrete by Slant Shear (Withdrawn 2008)*. ASTM International, West Conshohocken.

ASTM C1059/C1059M-99, 1999. *Standard Specification for Latex Agents for Bonding Fresh To Hardened Concret*e. ASTM International, West Conshohocken.

ASTM C150/C150M-02, 2002. *Standard Specification for Portland Cement*. ASTM International, West Conshohocken.

Essa, M., Abdul-Amir, A. and Hassan, N., 2012. Effect of ading (SBR) on concrete properties and bond between old and new concrete. *Kufa Journal of Engineering,* 4(1), pp.81-95.

Noori, Z., 2016. Compaction and shear behaviour of low plasticity clayey soils treated by crushed lime. *International Journal of Engineering Technology, Management and Applied Sciences,* 4(6), pp.193-199.

Obla, K. H., "*What is Green Concrete*," Concrete InFocus, V. 8, No. 2, Spring 2009. Available from: https://www.nrmca.org/research_engineering/Documents/What_is_Green_Concrete.pdf. [Last accessed on 2016 Sep 26].

Tarun, R., Canpolat, F. and Chun, Y., 2003. Limestone Powder Use in Cement and Concrete, Report No. CBU-2003-31, REP-525. Available from: http://www4.uwm.edu/cbu/Papers/2003%20CBU%20Reports/REP-525.pdf. [Last accessed on 2016 Nov 10].

Thongsanitgarn, P., Wongkeo, W., Sinthupinyo, S. and Chaipanich, A., 2011. *Effect of Limestone Powders on Compressive Strength and Setting Time of Portland-Limestone Cement Pastes*. Tiche International Conference 2011, November 10-11, At Hatyai, Songkhla Thailand.

Wang, R., Wang, M. and Li, X.G., 2005. Physical and mechanical properties of styrene-butadiene rubber emulsion modified cement mortars. *Journal Cement and Concrete Research,* 35, pp.900-906.

Yao, S. and Ge, Y., 2012. Effect of styrene butadiene rubber latex on mortar and concrete properties. *Advanced Engineering Forum,* 5, pp.283-288.