Journal of Building Material Science
https://ojs.bilpublishing.com/index.php/jbms

ARTICLE

Impact of Polymer Coating on the Flexural Strength and Deflection Characteristics of Fiber-Reinforced Concrete Beams

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ARTICLE INFO

Article history
Received: 6 December 2022
Revised: 23 December 2022
Accepted: 9 January 2022
Published Online: 12 January 2022

Keywords:
Concrete coating
Liquid polymers
Flexural strength
Deflection
Magnetic induction

ABSTRACT

Liquid polymers (LP) have become an important structural material used in the construction industry in the last decade. This paper investigates the viability of using commercially available LPs as a coating material to improve the flexural strength of fiber-modified concrete beams. The scope included preparing rectangular prism concrete beams with a concrete mixture including fly ash and fiber and coating them with four different liquid polymers at a uniform thickness following the curing process while one set of samples was maintained under the same conditions as a control group without coating. In addition, cylindrical samples were prepared to determine the compressive strength of the concrete mixture. Following the curing process in an unconfined open-air laboratory environment for another 28 days, concrete samples were tested to determine the flexural strength and deflection characteristics under center point loading equipment. The results revealed that all four coating types enhanced both the flexural strength and the average maximum deflection of the beams compared to the control group. While the enhancement in the flexural strength changed approximately between 5% and 36% depending on the coating type, the improvements in average maximum deflections varied between 3.7% and 28.4%.

1. Introduction

Concrete is used practically in any construction project, from buildings and roads to bridges and dams. With approximately 30 billion tons of annual consumption, it is the most used construction material all over the world [1,2]. For this purpose, it has been a major research topic for decades. Once designed, produced, and constructed properly, concrete is a very durable construction material and should not have any durability issues during its life cycle [3]. On the other hand, it was shown by experience that the desired long-term performance has generally not been accomplished due to the early failure of concrete structures [4]. As a naturally porous material regardless of the mix design, the durability of structural concrete is affected by mixture composition as well as the surface characteristics [5-7]. Sim-

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DOI: https://doi.org/10.30564/jbms.v4i2.5304

ilar to concrete, polymers are being used almost in any phase of construction projects. It is mostly used to repair concrete work in the construction industry due to its durability, low permeability, high strength, and resistance to freeze and thaw characteristics. The use of polymers in concrete for various applications has been gaining popularity in the construction industry. There are three such applications commonly used nowadays, namely, polymer concrete, polymer-modified concrete, and impregnated concrete. In polymer concrete, cementitious materials inside ordinary concrete are completely replaced by polymers, commonly polyester styrene, acrylics, and epoxies., and cured at a certain temperature level [8]. Polymer-modified concrete, which is acquired by integrating very limited type polymers such as polymer dispersions, and water-soluble polymers, into the concrete during the mixing phase can benefit from the positive change in water/cement ratio and increased workability by lubrication effect [9]. They limit or eliminate the movement of water as well as the spread of the micro-cracks available in concrete [10]. In polymer-impregnated concrete, the liquid polymer fills the voids in concrete by replacing the free water and forms a solid polymer that fills following the heat-curing process [11]. Thermoplastic polymers are most used to impregnate concrete [9]. With this process, the compressive strength of the concrete was enhanced three to four times more than the conventional Portland cement concrete [9]. According to American Concrete Institute, the optimum polymer amount should be calculated and used in the polymer-modified concrete since the excess or deficit polymer amount can create adverse effects on the concrete itself by creating air entrainment or decreasing the water-reducing properties, respectively [10]. However, their use has been limited due to relatively higher costs and softening effects under high temperatures [9]. Polymer coating of concrete is similar to polymer impregnation of concrete. However, it is only performed on the visible surfaces of concrete structures. The use of surface coatings, which works as an impervious barrier between the surface of concrete and the surrounding environment, has been an effective way to safeguard existing and new structures made out of concrete [3,12,13]. However, there are no established criteria to assess the performance and selection of the appropriate coating material for exposure conditions [14]. There are various polymer-based surface coatings in the concrete industry such as acrylics, urethanes, and epoxy, to improve certain characteristics. As technology advances, the polymer manufacturing process enhances and facilitates the use of polymers in a wide range of construction projects. For example, some studies focused on glass and carbon fiber-reinforced polymer coatings to reinforce concrete and masonry structures against blast loads [15,16] while some other researchers investigated the hydrophobic [17], self-healing [18,19] and waterproofing [20] properties of the polymer coatings. Some other studies explored the effectiveness of fiber-reinforced polymer coatings in retrofitting damaged concrete beams [21]. Most recent studies related to concrete coatings focus on the durability of concrete, protection against corrosion, and chemically aggressive environments to achieve the expected service life. The impact of concrete surface coating on the mechanical properties, especially the strength and deformation characteristics has not been investigated thoroughly. This paper tried to fill the gap by evaluating the flexural strength and deflection characteristics of fiber-reinforced short concrete beams coated using commercially available liquid polymers.

2. Objectives and Scope

Concrete is the second most used material on the earth following water. It used more than twice the amount of all other construction materials combined mainly thanks to its strength and affordability. The strength of concrete is lessened over time due to aging-related deterioration under various climatic and loading conditions. The strength of concrete is typically determined by the type and proportioning of its fundamental ingredients, and practically it cannot be increased once the hardening process is completed. The purpose of this research is to examine the impact of liquid polymer (LP) coating on the flexural strength and deflection characteristics of fiber-reinforced concrete beams (FRCBs). The objective of this study includes evaluating the flexural strength values of FRCBs after coating with four different commercially available liquid polymers at the optimum coating thickness. The scope of the research covers preparing 6” by 12” cylindrical samples to determine the characteristic compressive strength of the mixture and 6” by 6” by 21” rectangular prism samples to evaluate the flexural strength of control and coated mixtures. Four different commercially available LPs are used in this research. In addition, four different flexural strength replicates are prepared per LP. Non-destructive magnetic induction method is utilized to measure the coating thickness to ensure a uniform polymer coating thickness on each sample. The deflection and the loading data are recorded throughout the testing until the samples failed.

3. Materials and Methods

3.1 Materials

Materials used in this study were mainly obtained from local suppliers in the State of Michigan. The cement was selected as the commercially available type 1 Portland cement with a specific gravity of 3.15 and a specific surface area of 3150 cm^2/g. The initial and final setting times were 1 hour 50 minutes and 3 hours 40 minutes, respectively.

The water used for hydrating the concrete mixtures and curing concrete samples was the potable water provided by the City of Ypsilanti with an average pH value of 7.07. Crushed coarse aggregates with at least two angular faces and a nominal maximum aggregate size (NMAS) of 19 mm were selected while the fine aggregates composed of natural and crushed sand were used in the concrete mixes. To match the job mix formula gradation, 6.5% lime filler was added to the fine aggregate portion. Combined gradation information of the aggregates along with some other physical properties of both aggregate types are provided in Table 1.

Table 1. Gradation and physical properties of aggregates.

Sieve Size (ASTM E11)		**Percentage Passing**
Standard	Alternate	
25.0 mm	1 in.	100
19 mm	3/4 in.	96.1
12.5 mm	1/2 in.	82.7
9.5 mm	3/8 in.	71.3
4.75 mm	No. 4	60.6
2.36 mm	No. 8	47.1
1.18 mm	No. 16	31.1
0.6 mm	No. 30	20.9
0.3 mm	No. 50	13.0
0.15 mm	No. 100	8.6
0.075 mm	No. 200	4.4
Los Angeles Abrasion		27%
Nominal Maximum Aggregate Size (mm)		19
Dry Rodded Unit Weight of Coarse Aggregate		1646 kg/m^3 or 100.1 $lb./ft^3$
Specific Gravity of Fine Aggregates		2.639
Specific Gravity of Coarse Aggregates		2.662

To make a concrete mixture similar to the one used in the region's construction projects, fibers and fly ash were added to the mixture at certain percentages based on the concrete volumetric design and manufacturers' recommendations. Non-magnetic synthetic fibers were put in the concrete mixture to increase the flexural toughness of the beams produced. The fibers had an average length of around 50 mm with an equivalent diameter of 0.77 mm and a specific gravity of 0.91. Figure 1 illustrates the synthetic fibers incorporated into the concrete mix. Class C fly ash with a specific gravity of 2.52 and an average particle size of 15 microns replaced some of the cement in the mixture.

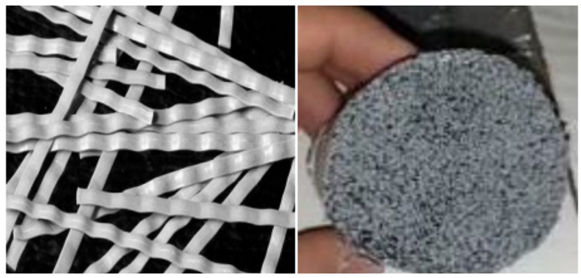

Figure 1. Synthetic fibers.

Liquid polymers used in this study were commercially available polyurethanes with the chemical name diphenylmethane di-isocyanates, water-based epoxy, and water-based organic polymer types. Since they are patented products, only certain information is available. Some of the chemical and physical properties provided by the manufacturer are given in Table 2.

Samples were maintained in a well-ventilated area following the application of the liquid polymer coatings to minimize the drying/curing time and avoid possible health hazards due to slight to mild odor.

3.2 Sample Preparation and Curing of Concrete Mixture

Single-source/single-batch materials, when possible,

Table 2. Properties of liquid polymers.

Analytical Properties	**Value/ Characteristics**			
	LP#1	LP#2	LP#3	LP#4
Color	Light Brown	Brownish	Extra White	White
Odor	Slight	Slight	Slight to Mild	Mild
Isocyanate Equivalent Weight	350	139	-	-
Viscocity @ 77 ^oF, centipoise	425	210	503	128
Specific Gravity @ 77 ^oF	1.16	1.23	1.42	0.99
Vapor Pressure @ 77 ^oF, (mm Hg)	$<10^{-5}$	$<10^{-5}$	$<10^{-5}$	$<10^{-5}$
Cleveland Open Cup Flash Point, ^oF	>230	>432	N/A	N/A
Solubility in water	Dilutable	Dilutable	Dilutable	Dilutable
Working time	Adjustable w/catalyst	4 hours	up to 8 hours	up to 24 hours

are used in the mix design to minimize the impact of source variability and focus merely on the impact of liquid polymers. Mix proportions are determined for a 4-inch slump following the absolute volume method. The water/cementitious material ratio was taken as 0.4, with cement occupying 9.3% of the mixture weight. Fresh concrete properties were measured to ensure consistency between the mixtures. The target air content was 6% and all samples had an air content changing between 5.2%-7.1%. The unit weight of the control concrete was 150.8 lb/ft^3 (pcf). Table 3 provides the concrete mix design proportions and per-sample weight in grams for the flexural strength samples.

Table 3. Concrete mix design proportions and per-sample weight.

Ingredients	Percentages in the mix	Per sample weight (gr)
Water (H_2O)	4.60%	1360
Cement (Type I)	9.30%	2720
Fly Ash (Class C)	2.30%	680
Fine Aggregates	27.90%	8160
Coarse Aggregates	55.70%	16330
Fiber (Synthetic)	0.15%	45
Total	100.00%	29295
water/cementitious	0.4	

Concrete ingredients were mixed in a laboratory-size concrete batching mixer to provide a uniform mixing for each sample. Ingredients were mixed for 5 minutes to obtain a homogeneous concrete mix. Lastly, the fibers were added to the mixer right after the mixing of the other ingredients was completed. As per the manufacturer's recommendation, the concrete was further mixed for another 70 revolutions to ensure the uniform distribution of the fibers throughout the concrete mixture. Following the mixing process, concrete was placed either into 6" by 12" cylindrical or 6" by 6" by 21" rectangular prism steel molds to prevent expansion. Cylindrical samples were placed into molds in three approximately equal layers whereas prismatic samples were placed in two equal lifts. Tamping and tapping of the layers for compaction, finishing and leveling the surface of the molds, and selection of the tools was performed according to the standard specification. Hardened concrete samples were unmolded and placed into a temperature-controlled circulatory water bath 24 hours after pouring the molds. Concrete samples were maintained in the water bath for another 28 days to complete the curing process as per standards. The temperature of the curing water was adjusted using a circulatory water heater at around 75^{o}F and when needed the water bath was topped with water to maintain the water level.

3.3 Application, Curing, and Thickness Measurement of Surface Coating

At the end of the curing period, some flexural strength samples were coated with liquid polymers whereas some prismatic samples were maintained as the control samples. The selection of samples to be coated and to be kept as control samples were performed randomly to prevent any sort of bias. Each polymer type was applied to 4 samples. Application of the liquid polymers was achieved using a roller brush. All four sides of the rectangular prism samples were coated with liquid polymers as shown in Figure 2.

Figure 2. Application of liquid polymer coating to rectangular prism concrete sample.

The number of roller passes per liquid polymer was investigated prior to the coating process to ensure the same thickness of the coating was applied to each sample. The thickness of the coatings was determined with an induction coating thickness gauge. Measurements were performed using the scan mode option, which allowed for checking the maximum, minimum, and average coating thicknesses on the entire surface. This process was repeated on four surfaces of all samples. The target coating thickness was set as 100 microns as per the literature. The coating thickness of all samples changed from 92 microns to 105 microns. While it took only 3 passes for the thickest liquid polymer to reach the target coating thickness, seven passes were applied to achieve the same coating thickness with a thinner liquid polymer. Hence, the number of passes ranged between 3 and 7 to reach approximately 100 microns of coating thickness. Following the coating, the samples were maintained in laboratory conditions for another 28 days before testing while the control samples were further cured during that time frame.

4. Performance Tests and Results

The flexural strength test was the main performance test conducted to determine the relative performance of the polymer-coated beams. The compressive strength of the unmodified concrete samples was also obtained for control purposes. Lastly, the change in deflection during the flexural strength tests was recorded for all specimens to provide a comparison between various coatings of this study.

4.1 Compressive Strength

To acquire the characteristic compressive strength of the concrete mixtures, six cylindrical samples having a 6-inch diameter and 12-inch height were prepared. Tests were conducted using a test mark automated loading-controlled compression testing machine. Prior to the testing, the diameter and length of each sample were measured and recorded at least two different locations perpendicular to each other. Any sample with more than a 2% difference in diameter readings was discarded. In addition, if the end faces of the samples were not flat by more than 0.5 degrees, which was the case most of the time, they were ground to meet the standards. Once the samples were ready for testing, they were placed inside the unbonded caps and testing was performed by loading the samples 35±7 psi/s as per ASTM C39 standard specifications. The test continued until the sample was broken and the maximum load carried by the sample was captured automatically by the testing equipment. Subsequently, the compressive strength values of the samples were calculated by simply dividing the recorded maximum load in pounds by the average cross-sectional area calculated using the previously measured diameters. Since the length-to-diameter ratio of the samples tested was 2.0, there was no need to apply correction factors to the results. Table 4 provides compressive strength test data along with basic descriptive statistical analysis results. The design characteristic compressive strength was 4,500 psi. The average compressive strength obtained at the end of the tests was 4,972 psi with only a 0.6% coefficient of variation.

Table 4. Characteristic compressive strength.

Sample Number	Load at Failure	Compressive Strength
	lbf	psi
#1	140057	4953
#2	141630	5009
#3	139832	4946
#4	141181	4993
#5	139607	4938
#6	141181	4993
Average Compressive Strength		4972
Standard Deviation (psi)		30
Coefficient of Variation (%)		0.60%

4.2 Flexural Strength

The flexural strength of plain/unreinforced concrete is seen as an indirect measure of its tensile strength. It is more affordable and easier than a tensile strength test even though the results are slightly different. It can be defined as the ability of concrete to resist bending deformation under a flexure test. There are different flexural strength setups used to determine the modulus of rupture (MOR) of concrete beams. It is an important parameter for the design of concrete beam and slab-like structures. In this study, MoR values were determined under a mid-point (a.k.a center point or three-point) loading setup by testing 6” by 6” by 21” prismatic concrete samples. The test starts by laying the specimen centered horizontally over two points of contact on the bed of the testing machine. A single force applying contact point connected to the head of the testing machine just in the center point. Once the sample is ready to be loaded, a contact load in the range of 3% to 6% of the estimated maximum load is applied to the sample for the gap check between the specimen and any contact points. The specimen is loaded continuously without creating any shock. The loading is maintained at a constant rate throughout the test duration. The specification states that the loading should be applied in a way to create stress on the tension face at a rate between 125 psi to 175 psi. The following formula is used to calculate the rate of loading.

$$r = \frac{2*S*b*d^2}{3*L} \quad (1)$$

where,

r: rate of loading in lb/min

S: rate of increase in extreme fiber stress (psi/min)

b: average specimen width (inches)

d: average specimen depth (inches)

L: span length (inches)

The average depth and width of the specimen are determined after the testing is performed. There are three measurements taken for each dimension, one at the left end, one at the right end, and one at the center of the cross-section. 0.05 inches of precision is required in the dimension measurements as per the specifications. Once the testing is completed, Equation (2) is used to compute the modulus of rupture.

$$R = \frac{3*P*L}{2*b*d^2} \quad (2)$$

where,

R: modulus of rupture in psi

P: maximum applied load recorded by the testing machine in lbf

L: span length (inches)

b: average specimen width at fracture point (inches)

d: average specimen depth at fracture point (inches)

Table 5 summarizes the maximum loads both in pounds-force (lbf) and kiloNewton (kN) for each sample that failed under the midpoint flexural strength test. Following the failure, samples were visually inspected for cracks, and width and depth measurements were taken from the cracked surface.

Similarly, Figure 3 illustrates the breaking loads in lbf as bar charts for (a) liquid polymer coating #1 (LP#1), (b) liquid polymer coating #2 (LP#2), (c) liquid polymer coating #3 (LP#3), and (d) liquid polymer #4 (LP#4), respectively. The red line in each graph corresponds to the average maximum load carried by control samples, which was equal to 5,593.25 lbf. All samples coated with liquid polymers carried higher loads compared to the uncoated samples other than LP#4- sample number (S#) 3, which carried only 54,66.4 lbf.

Table 5. Maximum load recorded during center point flexural strength test.

Specimen Type	Ultimate Load		Specimen Type	Ultimate Load	
	kN	lbf		kN	lbf
Control Sample#1	25.5	5721.4	Control Sample#2	24.3	5465.1
Coating LP#1-S#1	33.4	7515.4	Coating LP#3-S#1	28.6	6425.0
Coating LP#1-S#2	31.5	7077.0	Coating LP#3-S#2	28.6	6425.0
Coating LP#1-S#3	30.0	6739.8	Coating LP#3-S#3	31.5	7086.0
Coating LP#1-S#4	33.6	7546.8	Coating LP#3-S#4	28.9	6494.7
Coating LP#2-S#1	25.9	5811.3	Coating LP#4-S#1	29.9	6710.5
Coating LP#2-S#2	26.3	5912.5	Coating LP#4-S#2	27.9	6260.9
Coating LP#2-S#3	25.5	5721.4	Coating LP#4-S#3	24.3	5466.4
Coating LP#2-S#4	25.6	5750.6	Coating LP#4-S#4	26.4	5943.9

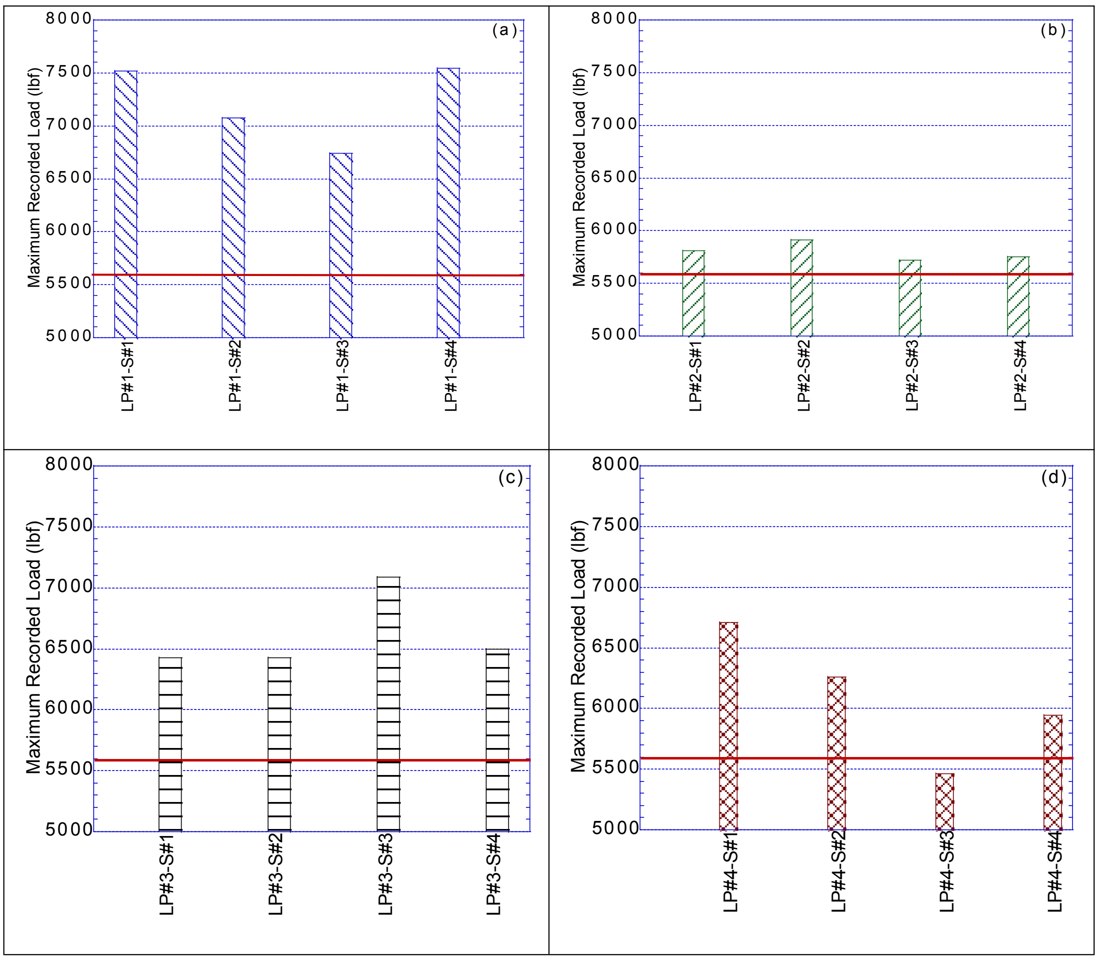

Figure 3. Maximum recorded load in psi for (a) liquid polymer#1 coating (b) liquid polymer#2 coating (c) liquid polymer#3 coating (d) liquid polymer#4 coating.

The flexural strength of the samples was calculated with the average width and depth of the prismatic samples obtained from broken cross sections using equation number 2. Following the modulus of rupture determination, the statistical significance test, also known as the t-test, was performed to determine the statistical significance of the test results. Tests were carried out between each group and results are provided in Table 6 along with an example t-test result table obtained between LP#1 and LP#2 mixture groups.

The P-value illustrated in bold in Table 6 is the most important result of the test. Since the t-tests were conducted based on a 95% confidence interval approach, the p-value less than 0.05 (5E-02) implies a statistically significant difference between the means of the trials. The bottom portion of Table 6 provided the p-values between each test group. According to the test result, there are statistical differences between the control and all coated mixtures as well as between all coated samples other than the LP#3 and LP#4 coatings, which yielded a p-value of 2.14E-1 > 5E-2.

Following the statistical significance test, basic statistical analysis was performed to determine possible outliers and/or extreme outliers. The rest of the data was used to conduct the descriptive statistical analysis for each coating type and control group. The average values per each data group along with the standard deviation bars are presented in Figure 4. The average, maximum and minimum values for the control group were marked in Figure 4 as well. Regardless of the liquid polymer coating type, all coatings improved the flexural strength values of the control mixture. In addition, the results illustrated that LP#1 coating improved the flexural strength of the concrete by around 264 psi, which corresponds to approximately a 36% increase compared to the control group. Similarly, LP#2, LP#3, and LP#4 advanced the modulus of rupture values by about 5%, 22%, and 17%, respectively.

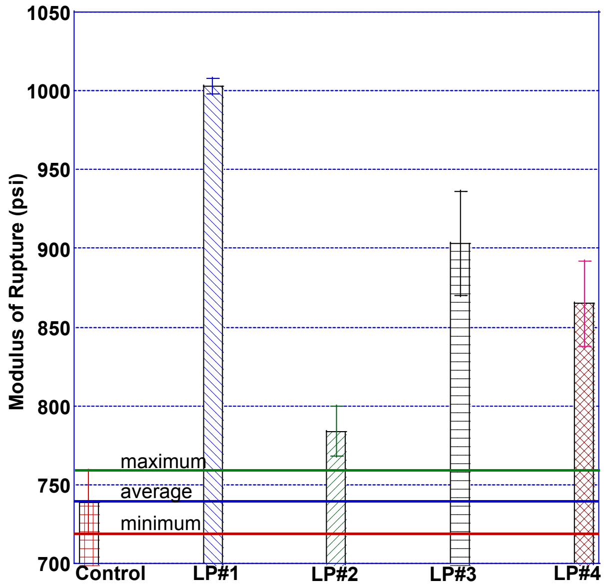

Figure 4. Average modulus of rupture (psi) values of control and liquid polymer coated prismatic concrete samples.

Table 6. t-test result between test groups with an example for LP#1 and LP#2.

t-Test: Two-Sample Assuming Equal Variances			LP #1	LP #2
Mean			967.9822287	773.5751073
Variance			1932.548475	268.4760421
Observations			4	4
Pooled Variance			1100.512259	
Hypothesized Mean Difference			0	
df			6	
t Stat			8.287618005	
P(T<=t) one-tail			8.35832E-05	
t Critical one-tail			1.943180281	
P(T<=t) two-tail			0.000167166	*Check <0.05*
t Critical two-tail			2.446911851	
Control Mixture				
LP#1 Coating	6.87E-05			
LP#2 Coating	2.63E-02	1.67E-04		
LP#3 Coating	1.90E-04	1.91E-02	8.00E-04	
LP#4 Coating	1.98E-03	1.24E-02	2.01E-02	2.14E-01

4.3 Deflection-Time

Serviceability is another important parameter that needs to be checked to ensure that concrete structures are stable. To meet the criteria set by the serviceability limit state, a concrete structure must remain serviceable throughout its design life by fulfilling its function. During the flexural strength test, other than the applied load, time and deflection values were also recorded. The change in deflection with time for each coating type is shown in Figure 5 along with the average deflection value obtained for the control mixture. Figures 5(a), (b), (c) and (d) illustrate the change in deflection with time for LP#1, LP#2, LP#3, and LP#4 samples, respectively. The deflection values were computed using the analytical approach to compare the recorded values. Equation (3) was applied to calculate the maximum deflection values.

$$\Delta max = \frac{P*L^3}{48*E*I} \tag{3}$$

where,

Δ_{max}: maximum deflection (in.)

P: maximum applied load recorded by the testing machine (lbf)

L: span length (in.), 18 in.

E: elastic/Young's modulus of concrete (psi), 4 million psi

I: Moment of inertia (in^4), approximately 108 in^4

The modulus of elasticity was calculated using the stress versus strain curves acquired during the compressive strength test. Based on the result, it was approximated to 4 million psi even though it showed minor changes

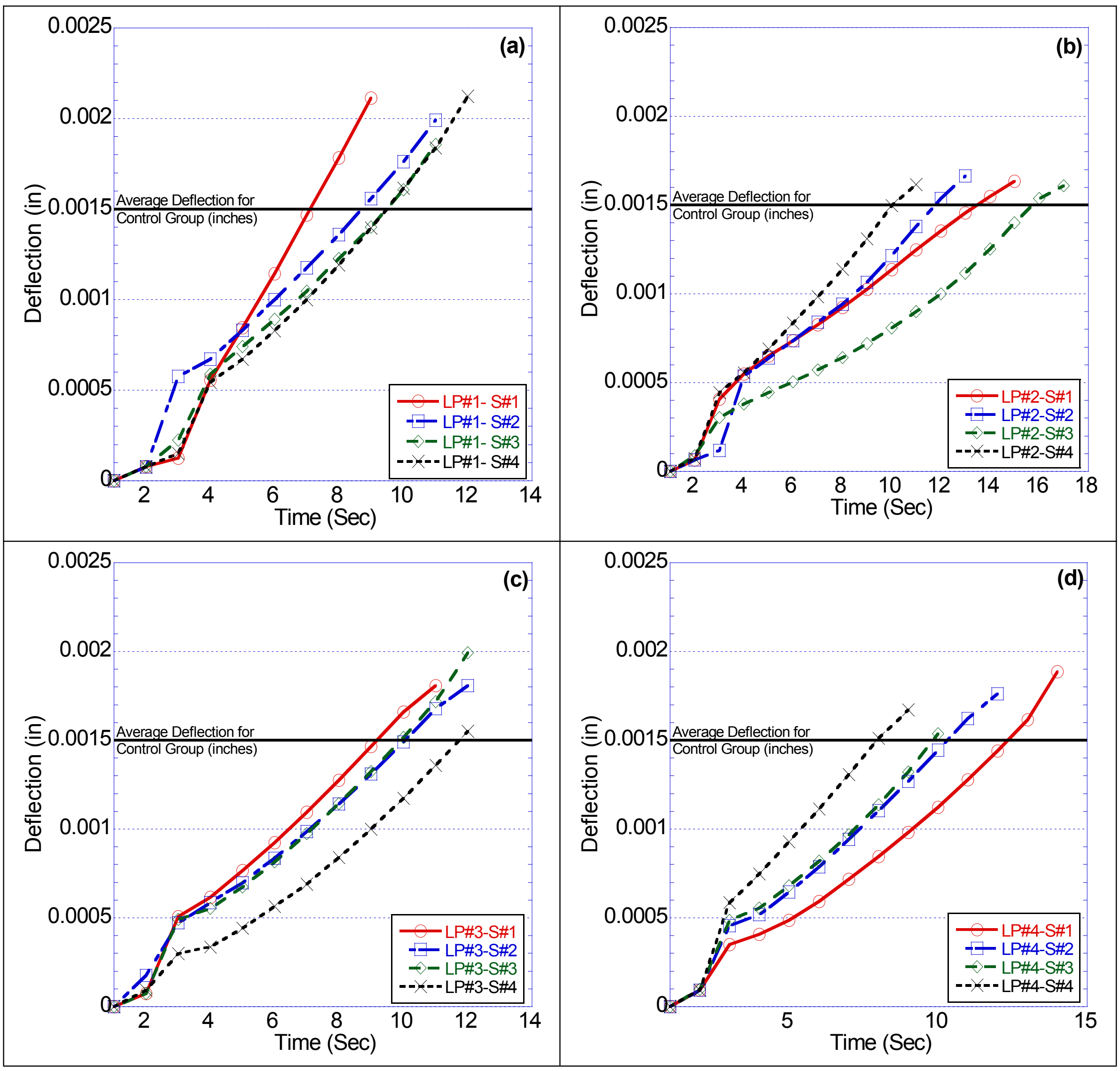

Figure 5. Change in deflection over time for (a) liquid polymer#1 coating (b) liquid polymer#2 coating (c) liquid polymer#3 coating (d) liquid polymer#4 coating.

per polymer coating type. Elastic modulus was taken to be the same for all samples tested. The moment of inertia, around 108 in^4, slightly changed for each sample depending on the average width and depth measurements. The span length was taken as 18 inches based on the distance between the support points of the testing apparatus.

Similar to the flexural strength test results, statistical significance tests, determination of outliers and/or extreme outliers as well as the descriptive statistical analysis were performed for deflection values. Table 7 summarizes both maximum and average deflection values for each coating type and control mixture group along with the percent change in deflection compared to the control mixture. The results show that polymer coatings improved the average deflection regardless of the coating type. While LP#1 coating increased the average deflection by 28.4% and maximum deflection by 27.0%, LP#2. LP#3 and LP#4 coatings enhanced the average deflection by 3.7%, 15.3%, and 16.0%, respectively.

Table 7. Maximum and average deflection values.

	Deflection (in)		**Change in Deflection (%)**	
	Average	Maximum	Average	Maximum
Control Group	0.001573	0.001672	-	-
LP#1 Coating	0.002021	0.002123	28.4%	27.0%
LP#2 Coating	0.001631	0.001664	3.7%	–0.5%
LP#3 Coating	0.001814	0.001827	15.3%	9.3%
LP#4 Coating	0.001824	0.001887	16.0%	12.9%

5. Conclusions & Recommendations

This research paper presented the findings of liquid polymer coating of fiber-reinforced concrete beams. Four commercially available polymer coatings with different physical properties were selected for this study. The flexural strength and deflection versus time characteristics using a mid-point test setup were determined to compare the impact of coatings relative to the control concrete mix design. Statistical significance tests were conducted to check if the results obtained were statistically different. The following conclusions can be withdrawn based on the results of this research study.

- The characteristic compressive strength with 4500 psi was designed and the average 28-day compressive strength of the mix design was obtained as 4972 psi.
- All liquid polymer-coated samples other than LP#4-S#3 carried higher loads than the uncoated/control samples.
- The statistical significance test results showed that all coated mixtures were statistically different from the control mixture based on a 95% confidence interval. Moreover, all coated mixtures other than between LP#3 and LP#4 were statistically different as well.
- Regardless of the coating type, all coatings enhanced the flexural strength values compared to the control mixture. While LP#1 coating achieved an average flexural strength increase of around 36%, LP#2, LP#3 and LP#4 coatings enhanced it by approximately 5%, 22%, and 17%, respectively.
- Similarly, all coating types improved the average deflection values. LP#1 coating increased the average deflection by 28.4% whereas LP#2. LP#3 and LP#4 coatings enhanced the average deflection by 3.7%, 15.3%, and 16.0%, respectively.

Conflict of Interest

There is no conflict of interest.

References

[1] Anonymous, 2021. Concrete needs to lose its colossal carbon footprint. The International Journal of Science. 597, 593-594.

[2] EMC Cement, 2022. The Scale of Concrete [Internet] [Accessed 2022 Nov 24]. Available from: https://lowcarboncement.com/the-scale-of-concrete.

[3] Aguiar, J.B., Camoes, A., Moreira, P.M., 2008. Coatings for concrete protection against aggressive environments. Journal of Advanced Concrete Technology. 6(1), 243-250.

[4] Rodrigues, M.P., Costa, M.R.N., Mendes, A.M., et al., 2000. Effectiveness of surface coatings to protect reinforced concrete in marine environments. Materials and Structures. 33, 618-626.

[5] Kropp, J., Hilsdorf, H. (editors), 1995. Performance criteria for concrete durability : State of the art report prepared by RILEM Technical Committee TC 116-PCD. Performance of Concrete as a Criterion of its Durability. E & FN Spon: London.

[6] Zhao, Z., Qu, X., Li, J., 2020. Application of polymer modified cementitious coatings (PCCs) for impermeability enhancement of concrete. Construction and Building Materials. 249, 118769.

[7] Ahmed, A., Guo, S., Zhang. Z., et al., 2020. A review on durability of fiber reinforced polymer (FRP) bars reinforced seawater sea sand concrete. Construction and Building Materials. 256, 119484.

[8] Li, Z., 2011. Advanced concrete technology. John Willey and Sons, Hoboken, NJ: USA.

[9] Deshrousses, R., Soliman, A. (editors), 2018. The

uses of polymers in concrete: Potentials and difficulties. Building Tomorrow's Society; 2018 Jun 13-16; Fredericton, Canada. Canada: CSCE SCGC.

[10] ACI committee 548, polymers in concrete, 2009. Report on Polymer Modified Concrete. American Concrete Committee Reports. ACI 548.3R-09. 1-40.

[11] Gambhir, M.L., 2008. Concrete technology. McGraw Hill Education: Patiala, India.

[12] Elsayed, M., Elsokkary, T., Shohide, M., et al., 2019. Surface protection of concrete by new protective coating. Construction and Building Materials. 220, 245-252.

[13] Chi, J., Zhang, G., Xie, Q., et al., 2020. High performance epoxy coating with cross-linkable solvent via Diels-Alder reaction for anti-corrosion of concrete. Progress in Organic Coatings. 139, 105473.

[14] Almusallam, A., Khan, F.M., Maslehuddin, M., 2002. Performance of concrete coatings under varying exposure conditions. Materials and Structures. 35, 487-494.

[15] Urgessa, G.S., Esfandiari, M., 2018. Review of polymer coatings used for blast strengthening of reinforced concrete and masonry structures. Taha, M. (editor) International Congress on Polymers in Concrete (ICPIC 2018). Springer: Berlin/Heidelberg, Germany.
DOI: https://doi.org/10.1007/978-3-319-78175-4_91

[16] Irshidat, M., Al-Ostaz, A., Cheng, H.D., et al., 2011. Nanoparticle reinforced polymer for blast protection of unreinforced masonry wall: Laboratory blast load simulation and design models. Journal of Structural Engineering. 137(10), 1193-1204.

[17] Liu, L., Zhao, P., Liang, C., et al., 2022. Assessment and mechanism of inorganic hydrophobic flake incorporated into a polymer-modified cement-based coating. Journal of Building Engineering. 60, 105185.

[18] Tran, N., Nguyen, T., Ngo, T., 2022. The role of organic polymer modifiers in cementitious systems towards durable and resilient infrastructures: A systematic review. Construction and Building Materials. 360, 129562.

[19] Cho, S., White, S.R., Braun, P.U., 2009. Self-healing polymer coatings. Advanced Materials. 21(6), 645-649.
DOI: https://doi.org/10.1002/adma.200802008

[20] Cho, B.H., Nam, B.H., Seo, S., et al., 2019. Waterproofing performance of waterstop with adhesive bonding used at joints of underground concrete structures. Construction and Building Materials. 221, 491-500.