Anbar Journal of Engineering Science (AJES)
P-ISSN: 1997-9428; E-ISSN: 2706-7440

Vol. 12 , No. 2 (2021) , pp. 168 ~176
DOI: 10.37649/aengs.2021.171185

University of Anbar

Anbar Journal Of Engineering Science©

journal homepage: http:// http://www.uoanbar.edu.iq/Evaluate/

Effect of Polymer SBR on Strength Reduction in Concrete Immersed in Drainage and Ground Water

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PAPER INFO

Paper history:
Received 15/8/2021
Received in revised form 10/9/2021
Accepted 14 /9/2021

Keywords:
compressive strength, deterioration, drainage, ground water, SBR polymer, polymer modified concrete PMC.

ABSTRACT

Concrete structures suffer from the impact of many harmful attacking materials that affect the properties of the main material in them, which is concrete. These structures are also, exposed to the negative impact of many hostile environments such as soils containing harmful salts and harmful acids. A number of precautions should be considered in order to protect the concrete used in such structures. Adding polymer to concrete components as a percentages weight of cement is one of the methods for producing polymer-modified concrete, which has low permeability, better mechanical properties and is more resistant to the negative effects of harmful environmental factors. The utilization of polymers could help in protecting structures and enhancing concrete strength. In this study, concrete mixes were prepared with inclusion of styrene butadiene rubber (SBR) polymer at four percentages (0%, 5%, 7% and 10% by cement weight). Co-polymers of butidine with styrene (styrene-butadine rubber (SBR)), are a group of large-volume synthetic rubbers. High adhesion occurs between the polymer films that form and cement hydrates. This action gives improves the properties of concrete such as flexural and compressive strength and gives also a higher durability. The investigation was extended to evaluate the compressive strength of the SBR concrete mixes immersed in three types of waters: tap, drainage and ground water, at three different ages. The results showed that SBR polymer enhanced the compressive strength of concrete significantly. A comparison between reduction in strength of concretes immersed in these three types of waters was also presented. Moreover, the presence of SBR polymer led to reduced loss in strength of concrete specimens immersed in drainage and ground water. A proposed model to determine the compressive strength of concrete specimens immersed in drainage and ground waters was deduced. This model could be a helpful tool for rapid and easy estimation of the strength of concrete specimens immersed in drainage and ground water at different contents of SBR polymer. The results showed the highest improve in compressive strength to be associated with 7% SBR mixes at the three tested ages. The increases in this strength at days 7, 28 and 56 with inclusion of 7% SBR polymer were 112.8%, 113.9% and 116%, respectively, compared to OPC mix.

1. Introduction

Deterioration of concrete strength due to chemical attack from water or soils can occur throughout the life of concrete structures. Deterioration of concrete increases the cost of repairing and maintaining private and public buildings and structures. Concrete is widely used for constructing drainage canals and trench drains.

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In most cases, concrete with low to moderate strength (low content) is used to produce these conveying systems to avoid increasing the cost of projects. Therefore, after a few years of use, this infrastructure sustains severe damage or collapses.

The reduction in the strength of concrete subjected to various kinds of impure water (groundwater, wastewater, and drain water) has been studied by a number of researchers [Y.-S. Park, et al, 1999] [1]. Laboratory tests have been carried out to evaluate the deterioration resulted from the chemical attack by both magnesium and sodium sulfates on two types of concrete: normal and high strength [1]. The sulfate attack on both types of concrete was evaluated in terms of compressive strength as well as linear expansion and loss in weight. The results of this work confirmed that sodium sulfate and magnesium sulfate cause the damage of concrete. Moreover, the reduction in compressive strength resulted from the magnesium sulfate effect was greater than did the sodium sulfate. Al-Harithi et al. [2] reported that the compressive strength of flowable fill cement mixture declined significantly when prepared with groundwater instead of fresh tap water. Nevertheless, the produced mix exhibited an acceptable strength of 0.35–3.5 MPa at 28 days of age.

Styrene Butadiene Rubber (SBR) Polymer Modified Concrete: SBR Polymer is the most widely used in concrete. Co-polymers of butadiene with styrene (styrene-butadine rubber (SBR)), are a group of large-volume synthetic rubbers[3]. High adhesion occurs between the polymer films that form and cement hydrates. This action gives less strain compared to ordinary concrete and improves the properties of concrete such as flexural and compressive strength and gives also a higher durability [4].

The use of polymers in concrete has broadly increased in recent times. One such polymer is Styrene Butadiene Rubber (SBR) polymer, which can be successfully combined with different engineering materials. The use of SBR in concrete has been previously investigated by a number of authors [5-12].

A. Antonio , N. C. Andrade, 2006 [13] analyzed the protection capacity of modified Portland cement mortar with some types of polymers like: styrene butadiene, acrylic latex with reinforced plastic fibres and acrylic latex with silica fume, using the electrochemical polarization resistance (Rp) technique to monitor the behavior of steel bars embedded in the specimens, when placed in environments with CO2 and chloride. Results of this research indicated that, only chemical, physical and mechanical characterizations are not sufficient to classify these materials from the point of view of protection against aggressive agents.

In another study, Truong et al. [14] reported that the use of 15% polymer improved the compressive strength at an early age, with a 91% ratio of compressive strength at day 7 to that of day 28. Additionally, the time until the development of cracks was delayed, and the final crack value was reduced.

The use of the polymer SBR in the modification of concrete resistance to sulfate attack has been investigated recently [15]. The study concluded that polymer–cement composites showed an improved resistance to attack from sulfate ions compared with unmodified cement mortar. It was reported that the loss of compressive strength of the modified polymer–cement composite (P/C 0.2) was 18%, compared with 44% for that of unmodified composite, indicating a low reduction in strength and improved durability properties.

Based on the above, data on the effect of SBR polymer on concrete subjected to the impact of drainage and ground waters is still lacking. This study aims to investigate the effect of SBR polymer on the reduction in compressive strength of normal concrete subjected to three types of water: tap, drainage and ground waters. The percentages of SBR polymer used were 5%, 7% and 10%. Investigations on compressive strengths at three ages were presented. Determining the optimum content of SBR polymer is one of the main goals of this study. Moreover, for fast and rapid estimation of SBR content in concrete, a prediction model was presented for each type of water.

2. Experimental program

2.1 Materials

Cement, coarse aggregate (gravel), natural sand, and water were used for preparation of the design concrete mixes. Ordinary Portland cement (OPC) type 1 with accordance to the requirements of ASTM C 150 [16]. The chemical composition of OPC cement is presented in Table 1. The physical properties of thee used cement are listed in Table 2. Coarse aggregate (gravel) having a rounded shape with maximum size of 10 mm and, the grading of this aggregate conforms to ASTM C33 [17]. The water absorption is 1.0%. and the specific gravity of 2.64. Natural river sand was used as fine aggregates having a maximum size of 4.75 mm. The specific gravity of this sand is 2.63, and the water absorption of 3.5%.

The sieve analysis of the used aggregates (coarse and fine) are as shown in Fig. 1.

In order to prepare polymer concrete mixes, Styrene Butadiene Rubber (SBR) polymer was used without any treatment. The physical properties of the SBR polymer are listed in Table 3.

Table 1. The chemical composition of Ordinary Portland cement.

Table 2. The physical properties of the cement.*

Component	% by weight
CaO	63.94
SiO_2	21.16
AL_2O_3	5.00
Fe_2O_3	3.8
SO_3	2.26
MgO	1.65
Alkalies	.04
L.O.I.	1.5
I.R.	0.3

Property	Results	Limits of ASTM C150
Specific surface area (Blaine method),m^2/kg	354	260-430
Setting time by Vicat's ethod		
Initial (minutes)	1:22	≥ 45 min.
Final (hour: minutes)	4:50	≤ 6.25 hr:min
Compressive strength (50 mm cube) [/mm^2)		
3days	22.0	≥12
7days	31.3	≥19
Soundness (autoclave method) %	0.3	≤0.8

*Tests have been done in the concrete Lab., Civil Engineering Dept., College of Engineering, University of Anbar.

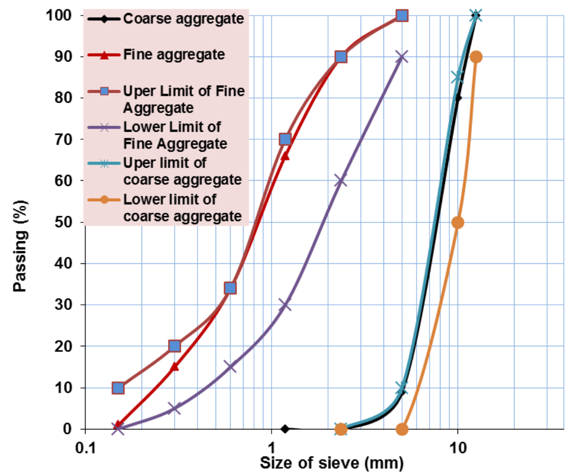

Figure 1. grading curves of fine and coarse aggregates.

Table 3. Physical properties of SBR polymer

S.G.(20°)	Color	pH	Viscosity (20°, cps)	Total solids (wt%)	Touch dry time (hrs)
1.12	Milky white	6	20	25	5

2.2 Mixing proportions

The proportions of the prepared mixes are listed in Table 4. The reference mix consists of 1:2:4 (cement: sand: coarse aggregate) and water to cement ratio of 0.45. Polymer mixes were prepared by adding a specific amount of SBR polymer. The selected amounts of SBR polymers were 5%, 7% and 10% by weight of cement. Water to cement ratio was fixed for all polymer mixes. Water was used to obtain the appropriate consistency for the concrete mix.

Table 4. Mix proportions (kg/m^3)

Mix	C	CA	FA	W/C	SBR
OPC	370	1477	739	165	-
SBR 5%	370	1477	739	163	18.5
SBR 7%	370	1477	739	160	26.0

SBR 10%	370	1477	739	158	37.0

2.3 Mixing, casting and testing

The mixing process was based on the same procedure used Al-Hadithi, 2005 [18]. Mixing of concrete started by inclusion of the dry components (gravel and sand) for two minutes to ensure good distribution of aggregate. Cement was added with water and SBR polymer for mixes with 5%, 7% and 10% polymer content. The mixing was continued for another three minutes to achieve an adequate consistency for the prepared mixes. Finally, the remaining water was added to the mix. The workability of all concrete mixes was measured immediately after mixing using slump test according to the procedure described in ASTM C143–03[19]. The design slump was 80 ± 10 mm. For each mix, twenty seven cubes were cast. The dimensions of the cubes were 10 cm × 10 cm × 10 cm. The total number of cubes prepared in this study is 108. Fresh concrete cubes are shown in Fig. 2.

The deterioration in strength of concrete immersed in drainage and ground water was evaluated through compressive strength test. The prepared specimens were immersed in three types of water: fresh tap water, drainage water and ground water. Table 5 presents the chemical composition and pH value for each type of water. The compressive strength test was conducted using ELE machine with 1000 kN capacity. The average compressive strength for each mix was calculated as the load per area of loaded face. This test was in accordance to the requirements of the British standards B.S.1881:116 [20].

Figure 2. concrete cubes in fresh state.

Table 5. Chemical composition of the selected types of water.

Property	Fresh tap water	Drainage water	Ground water
pH	7.٤١	8.01	8.3٠
Na^{+}%	0.003	0.057	0.048
K^{+}%	0.0002	0.006	0.0٢٩
Ca^{+2}%	0.03٥	0.045	0.03٥
Mg^{+2}%	0.00٧	0.053	0.04٠
Cl^{-}%	0.00٧	0.184	0.0٦٠
HCO_3%	0.001	0.021	0.01١
SO_3%	0.03٢	0.51	0.3٠٠

3.Results and discussions

The compressive strengths for each mix were determined at three different ages, 7, 28 and 56 days. Results from compressive strengths test are presented in Table 6. The effect of polymer SBR on strength was investigated. The parameters investigated in this study were: effect of type of water on strength improvement, and effect of polymer SBR. Finally, to determine the optimum content of polymer SBR, prediction models are presented.

3.1Strength improvement for ordinary Portland cement concrete

As shown in Fig. 3. concrete strength developed with time for all different mixes. The increases in compressive strengths at 28 and 56 days of age for concrete cubes immersed in the three types of water were calculated and compared to those at 7 days of age.

For cubes exposed to tap water at 28 and 56 days of age, the increases in strength were 34.8% and 44.5%, respectively. Meanwhile, the increases in strength at 28 days of age were 68.8% and 24.5% for cubes immersed in drainage and ground water, respectively.

After 56 days of immersion in drainage and ground water, the ratios of increases in strength were 5.5% and 28.4%, respectively.
Clearly, different gains in strength after immersing concrete in the three types of water were observed. The lowest improvement in strength was for concrete cubes subjected to drainage water for 56 days. For concrete cubes

Table 6. Results of compressive strengths (MPa) tests at three ages (7, 28 and 56 days) for different mixes.

Mix	Compressive strength at 7 days age (MPa)			Compressive strength at 28 days age (MPa)			56 days			Increment in compressive concrete from 28 days according to 7 days (%)			Increment in compressive concrete from 56 days according to 7 days (%)		
	Fresh water	Drainage water	Ground water	Fresh water	Drainage water	Ground water	Fresh water	Drainage water	Ground water	Fresh water	Drainage water	Ground water	Fresh water	Drainage water	Ground water
OPC	26.73	15.46	24.9	36.04	26.1	31.01	38.63	28.2	31.96	34.83	68.82	24.53	44.52	82.41	28.35
SBR 5%	41.03	33.22	33.68	48.32	34.69	39.2	53.11	33.69	42.97	17.77	4.43	16.39	29.44	1.41	27.58
SBR 7%	56.87	49.74	45	57.17	49.6	52	57.73	49.47	55.1	0.527	-0.28	15.56	1.51	-0.54	22.44
SBR 10%	36.03	29.37	31.61	42.57	32.24	35.74	42.91	33.53	36.01	18.16	9.78	13.07	19.11	14.16	13.92

subjected to ground water, the increase in strength was lower than that of specimens submerged in fresh water. However, the strength improvement in concrete submerged in ground water was within the acceptable limits, or could be acceptable.

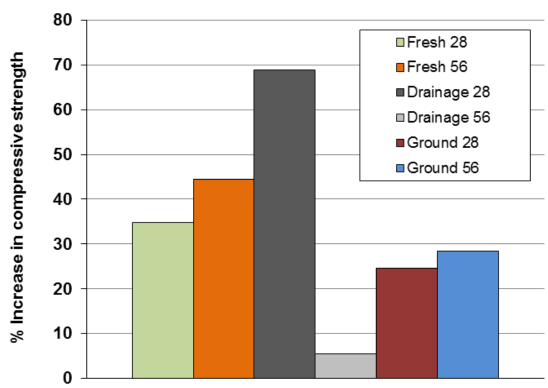

Figure 3. percentage of increase in compressive strength for fresh, drainage and ground water at 28 and 56 days age.

3.2 *Loss in strength for ordinary Portland cement concrete*

Figure 4 shows the effect of the type of water on the compressive strength of concrete at three ages: 7, 28 and 56 days. The obtained results showed that the concrete compressive strength reduced for mixes submerged in drainage and ground waters compared with the mix submerged in fresh tap water. After 7 days of exposure to drainage water, a significant loss in strength of 42.2% was observed compared to that of the cubes immersed in fresh water. At same age, a slight decrease in concrete compressive strength of 6.8% for cubes immersed in ground water was observed. The reductions in strength at 28 days were 27% and 11%, for concrete mixes exposed to drainage and ground water, respectively. At 56 days, concrete immersed in drainage water did not exhibit any considerable change, while this loss in strength increased to 17.3% for concrete submerged in ground water.

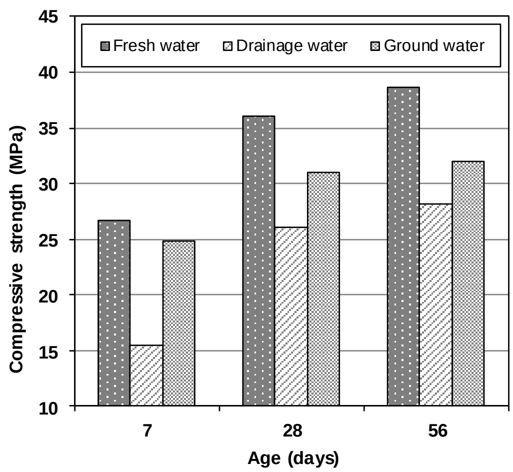

Figure 4. compressive strength for fresh, drainage and ground water at 7, 28 and 56 days age.

Obviously, the reduction in the compressive strength increased over time for concrete immersed in ground water, whereas for concrete in drainage water, the rate of loss in strength decreased. This could be ascribed to the strong effect of the sulfates in drainage water at an early age, while the effect would have been smaller in the ground water due to the low sulfate content. In general, the reduction in strength for concrete immersed in drainage water was higher than that of the concrete immersed in ground water due to the higher sulfate content in drainage water. However, the loss in strength was balanced by an improve in the compressive strength due to hydration [1] regardless of the type of water and immersion period.

3.3 *Effect of polymer SBR*

The effect of SBR polymer on concrete submerged in fresh, drainage and ground waters was also investigated. Results of the compressive strength test for SBR polymer mixes compared to normal concrete are shown in Figure 5. In general, SBR polymer enhanced the concrete compressive strength for mixes submerged in tap fresh water. However, the results showed the highest improve in compressive strength to be associated with 7% SBR mixes at the three tested ages. It is clear from the results that the compressive strength of all types of curing with different types of water was increased with an increase in the (polymer: cement) ratio to up to (7%) and then began to decline.

The increases in this strength at days 7, 28 and 56 with inclusion of 7% SBR polymer and cured by fresh water, were 112.8%, 58.63% and 37.48%, respectively, compared to OPC mix. The increases in this strength at days 7, 28 and 56 with inclusion of 7% SBR polymer and cured by drainage water, were 49.74%, 49.6% and 49.47%, respectively, compared to OPC mix. Whereas the increases in this strength at days 7, 28 and 56 with inclusion of 7% SBR polymer and cured by ground water, were 80.72%, 67.68% and 55.1%, respectively, compared to OPC mix.

The increase in concrete strength by inclusion of SBR polymer is attributed to the polymer particles that enhance the bonds between the mortar and aggregate [6]. Moreover, a higher sealing effect is exhibited with increased polymer resulting in improvement of compressive strength [21]. Another explanation for the enhancement in the concrete cube strength is the role of SBR particles in the compactness of the structure of cement paste [22]. However, the inclusion of a relatively high content of SBR polymer (10%) showed reduced strength, though still higher compared with the reference mix. This reduction in strength was attributed to the excessive increase in the air content of the concrete mix by inclusion of high amounts of SBR polymer [21, 23, 24].

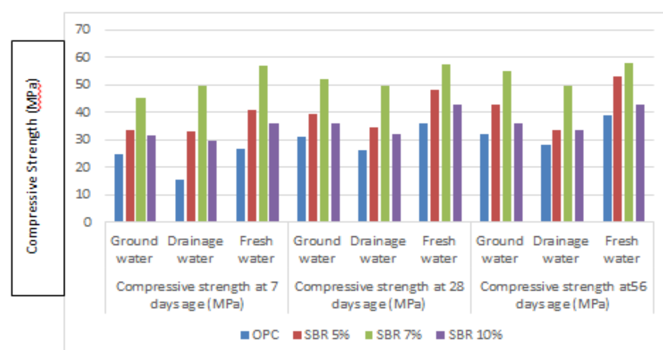

Figure 5. comparative of the compressive strength for the concrete mixes containing different percentages of SBR polymer

Figure 6 illustrates the effect of SBR polymer on concrete immersed in drainage water at three different ages (7, 28 and 56 days). Evidently, SBR content significantly affects the loss in concrete cube strength under compression. The compressive strengths at 7 days were reduced by 19%, 12.5% and 18.5% for SBR 5%, SBR 7% and SBR 10%, respectively, compared to the mixtures immersed in fresh concrete with the same SBR contents. At 28 days, the reduction percentages were 15.5%, 12.8%

and 10.5% for SBR 5%, SBR 7% and SBR 10%, respectively. At 56 days, the concrete exhibited strength reductions of 17.9%, 13% and 6.9% for SBR 5%, SBR 7% and SBR 10% mixes, respectively.

The reduction in the strength of such mixes was expected due to the effect of sulfates in the drainage water, as mentioned previously. However, the presence of SBR polymer lowered this loss in strength. SBR polymer improved the microstructure of the cement paste and reduced the calcium-silicate-hydrate (C-S-H) degradation. Moreover, it also reduced the volumetric expansion resulted from the formation of gypsum or (Ettringite) leading to interior cracks.

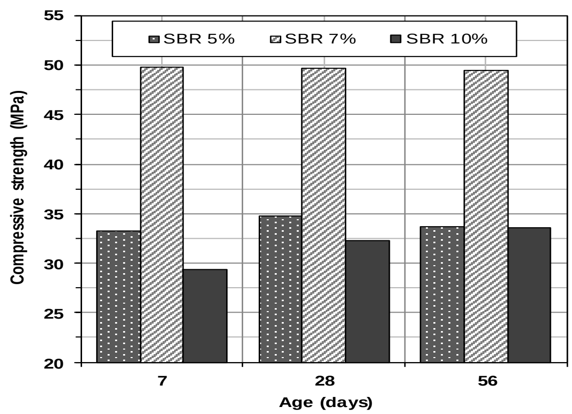

Figure 6. effect of SBR polymer on strength of concrete immersed in drainage water.

3.4 *Prediction models*

In order to promote the use of SBR polymer in concrete structures exposed to effects of drainage and ground water, proposed models for rapid and easy estimation of compressive strength of such concrete were presented in this study. The first model is used to predict the concrete compressive strength of SBR polymer mixes (SBR polymer up to 10% content) and immersed in fresh tap water, this model is based on a best fitting of the results of compressive strength testing. The suggested model is a 2nd degree polynomial and can be presented as follows:

$f_c = 35.44 + 5.9779\,S - 0.5125\,S^2$ *(1)*

$R^2 = 0.813$

Where

f_c is the compressive strength (MPa)

S is the SBR to cement percentage

The difference between the predicted and experimental values varies between approximately 1.6% and 9%. However, it has been reported that a 2nd degree polynomial is appropriate to illustrate the effect of SBR polymer on concrete [20]. Figure 7 shows the predicted vs. experimental values of compressive strength at 28 days.

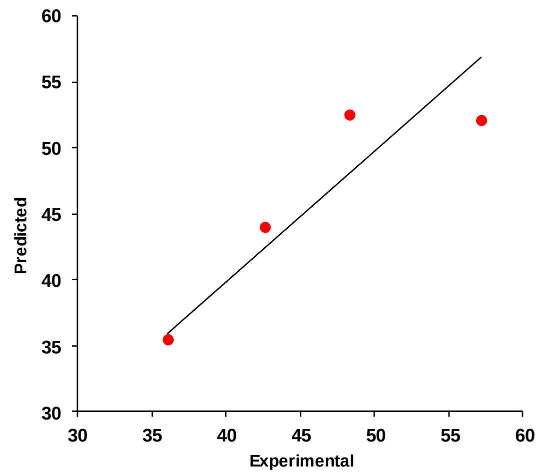

Figure 7. predicted Vs. experimental values of compressive strength.

For SBR polymer concrete immersed in the other two types of water, drainage and ground water, the prediction model can be expressed in the following equation:

$f_c = A + B\,S + C\,S^2$ *(2)*

Numeric values of the constants A, B and C from above equation are presented in Table 7. The regression correlation is also presented in the same table.

Table 7. Numeric values of constants A,B and C.

Type of water	A	B	C	R^2
Drainage	25.128	5.608	-0.467	0.705
Ground water	30.157	5.248	-0.450	0.725

Ultimately, concrete immersed in or exposed to drainage or ground water is subjected to strength deterioration, as explained above. The inclusion of SBR polymer can help alleviate this effect by balancing the deterioration with an enhancement of concrete strength. Further investigations on the long-term effects of drainage and ground waters on concrete strength in the presence of SBR polymer are needed. An analysis of SBR cost is also a critical aspect that will need to be studied in the future. Some of these aspects have been considered by the authors in their current work.

3. Conclusions

The following conclusions can be obtained:

1. An improvement in strength was attained for all concrete mixes immersed in the three types of waters; however, the increase in the compressive strength of concrete specimens immersed in ground water was the lowest.

2. Concrete compressive strength was reduced significantly for concrete mixes immersed in drainage and ground waters compared with the mix immersed in fresh tap water. In general, the reduction in strength for concrete immersed in drainage water was higher than that of concrete immersed in ground water. This is ascribed to the high sulfate content in drainage water.

3. The inclusion of SBR polymer in concrete enhanced the strength of ordinary concrete at the three contents adopted in this study.

4. The presence of SBR polymer in concrete led to reduced loss of strength loss for mixes immersed in both drainage and ground waters.

5. The optimum content of SBR polymer suitable for concrete subjected to drainage and ground water must be not less than 7%. This quantity of SBR is necessary to guarantee a low reduction in strength for concrete exposed to such types of waters. However, SBR polymer is expensive, and increasing its content in concrete mixes could increase the cost of the project. Further investigations into this parameter are suggested.

6. A proposed model to determine the compressive strength of concrete immersed in drainage and ground waters was presented. This model could be a helpful tool for rapid and easy estimation of the concrete strength of specimens immersed in drainage and ground waters and containing SBR polymer.

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