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Effect of Adding Styrene-Butadiene Rubber (SBR) on Corrosion Resistance for Reinforced Concrete Columns

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Abstract: Corrosion in steel bars significantly affects the concrete strength and durability. Problems, such as increasing the crack widths, deflections, increasing stresses, and decreasing concrete strength, are some consequences of steel corrosion. Therefore, preventing these undesirable consequences should be addressed. Some additive materials, which can be used in concrete, might be the most effective and affordable solution. In this research, Styrene Butadiene Rubber (SBR) was utilized in the concrete mixture to reduce water permeability in concrete. To test the effect of SBR on steel corrosion in structural members, seven reinforced concrete columns with a circular cross-section were cast with different contents of SBR, from one percent to six weight percent of water content. Using accelerated corrosion cells, major tests were conducted after twenty days. The results showed that using one percent of SBR improved the compressive strength of the concrete up to thirty – one percent. While using six percent of SBR increased the reinforced concrete columns' compression strength to about thirty-two percent. The concrete strength improved with adding SBR, the steel corrosion resistance increased, and the steel weight loss decreased. It was found that there was about a thirty percent improvement in steel weight for specimens with six percent of SBR. This ratio was even better for specimens with smaller steel bars in improving corrosion resistance, reaching about fifty-two percent.

تأثير إضافة مطاط ستايرين بوتادين (SBR) على مقاومة التآكل للأعمدة الخرسانية المسلحة

عاصم محمد لطيف، مهند ناطق الشنداح، حسام عبدالله العزاوي
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الخلاصة

للتآكل في حديد التسليح التأثير الأكبر على قوة تحمل الخرسانة بالإضافة إلى متانتها. اهم مشاكلها، زيادة عرض الشقوق، والانحرافات، وزيادة الضغوط وتقليل قوة الخرسانة، بالإضافة الى بعض عواقب تآكل حديد التسليح. لذلك، فإن منع هذه النتائج غير المرغوب فيها يحتاج إلى معالجة من قبل الباحثين. قد تكون بعض المواد المضافة التي يمكن استخدامها في الخرسانة هي الحل الرخيص الأكثر فعالية. في هذا البحث تم استخدام مطاط الستايرين بوتادين (SBR) في خليط الخرسانة لتقليل نفاذية الماء في الخرسانة. من أجل اختبار تأثير SBR على تآكل حديد التسليح في الأعضاء الهيكلية، تم صب سبعة أعمدة خرسانية مسلحة ذات مقطع عرضي دائري بمحتويات مختلفة من SBR، من واحد بالمائة إلى ستة بالمائة من محتوى الماء. باستخدام خلايا التآكل المتسارع، تم إجراء اختبارات رئيسية بعد عشرين يومًا. أظهرت النتائج أن SBR تحسّن مقاومة الضغط للخرسانة بنسبة تصل إلى واحد وثلاثين بالمائة باستخدام واحد بالمائة من SBR. علاوة على ذلك، زادت مقاومة الانضغاط لأعمدة الخرسانة المسلحة بنحو اثنين وثلاثين بالمائة باستخدام ستة بالمائة من SBR. بالإضافة لذلك تحسنت قوة الخرسانة مع إضافة SBR وازادت مقاومة التآكل الحديد وانخفضت خسارة وزن الحديد. حيث وجد تحسن في وزن حديد التسليح بنسبة حوالي ثلاثون بالمائة مع نسب ست بالمائة من SBR. حيث كانت هذه النسب هي أفضل لحديد التسليح ذو الاقطار الاصغر حيث وصلت النسب الى حوالي اثنان وخمسون بالمائة.

الكلمات الدالة: مقاومة التآكل، أعمدة الخرسانة المسلحة، SBR.

1.INTRODUCTION

Corrosion is the deterioration of a material or its properties due to its interaction with external or internal influences, or it is the outcome of the interactions of two or more materials or their components in the presence of an auxiliary medium, such as heat, humidity, or salt. Furthermore, corrosion occurs in facilities slowly and quietly; however, the losses it causes are unimaginable. Many losses are material and economic, including wellness losses related to human health directly impacting them and the environment. Corrosion negatively impacts factories and several buildings, such as schools, hospitals, and power stations. Corrosion also impacts power transmission poles, bridges, roads, and airports. Its parts lead to a shorter life, a shorter validity period, and an increase in operational efficiency. Building corrosion affects the maintenance and operation costs, as well as the water transmission and distribution networks, pumping stations, and water storage, which are exposed to corrosion from within the transmission and distribution lines and their accessories, as well as the visible parts that are exposed to various environmental and climatic changes. Moreover, corrosion impacts private industrial structures in buildings or pipeline production. It was noticed a decrease in the level of production and product quality, also constant malfunctions that lead to high losses, and when cracking and corrosion begin in installations. Water entering by capillary pores in concrete is an issue that affects the corrosion of steel. To address this problem, an experimental study was carried out by Ayyoob et al. using different types of materials, such as SBR. Standard cubes of 150 × 150 × 150 mm were cast and tested to investigate the effect of SBR on their compressive strength. The results showed that adding 10% of SBR by the weight of cement decreased the permeability to 60% and reduced the compressive strength to about 5% [1]. Adding SBR to the mixture was a promising solution to produce concrete with low permeability and better compressive strength, according to an experimental study. The finding of Jameel et al. indicated that the best replacement ratio by weight of SBR was 7%, which can improve the compressive strength up to about 114% compared with normal concrete at the age of 28 days [2]. In the enhancement of mechanical properties of Engineered Cementitious Composites (ECC) using unoiled fibers, Azadmanesh et al. utilized polymers, such as Styrene Butadiene Rubber (SBR) and Ethylene Vinyl Acetate (EVA). Their study revealed significant improvements across several parameters. Tensile strain, compressive strength, and deflection at mid-span exhibited notable increases of over 3%, more than 47 MPa, and more than 9 mm, respectively [3,4]. To improve the properties of concrete against impact loadings (tensile strength) and impact resistance of concrete by three percent of SBR latex, i.e., 0%, 4%, and 8% by weight of cement, were used along with three aggregates sizes, 19 mm down, 10 mm down, and 4.75 mm down [5]. Apostolpoulos experimentally evaluated the impact of corrosion on the tensile mechanical properties of B500c (martensitic, ferritic-perlitic) ribbed steel rebar to 8-, 12-, 16-, and 18-mm diameter that has been artificially corroded for 10, 20, 30, 45, 60, 90, and 120 days. According to the laboratory tests, corrosive environment duration and rebar cross-sectional area size significantly impacted the specimens' strength and ductility degradation. Furthermore, the tensile mechanical properties before and after corrosion showed progressive variation and an important value decrease. The protracted salt spray exposure exacerbated the damage and created pits and notches, resulting in stress concentration points and a progressively lost ductility and available energy opportunity.

Also, anti-seismic designs and codes that ignore the influence of cross-section area, corrosion level, and mechanical behavior of steel reinforced could result in unpredictable performance during severe ground motion [6, 7]. Rasheeduzzafar et al. conducted a study to investigate the influence of three key parameters, i.e., concrete cover, concrete quality, and bar size, on the protection of reinforcing steel against corrosion. Among these factors, the cover-to-bar-diameter (e/d) ratio emerged as a more definitive indicator of corrosion protection against cracking than individual cover or bar diameter considerations. The significance of the internal concrete chlorides is evident from their presence in concrete right from the manufacturing stage, which emphasizes the critical role of the period before cracking in the propagation of corrosion, a pivotal phase in the structural service life. Consequently, clear cover specifications must incorporate the e/d ratio and consider bar magnitude to prevent inadequate and misleading design in terms of corrosion prevention. To quantify the corrosion resistance against cracking, a corrosion resistance factor (cf'c/d or c/dw) was introduced. This factor effectively measures the relative corrosion protection conferred by specific detailing and strength parameters [8, 9]. Additives are materials directly added to concrete during mixing to give it special characteristics that either accelerate or slow hardening to reduce the concrete cost and unalter the proportions of the mixture, improving workability, maintaining the temperature of the concrete mix, and reducing permeability. Maintenance of the structure's concrete parts prone to cracking and penetrating capillary cracks treatment. As a result, several sides have been painted with low-viscosity materials, such as epoxy materials that seep inside. The concrete surface must be completely dry and free of any concrete particles to avoid capillary cracks. Weak cracks in concrete can be repaired by injection, which fills internal cracks no matter how deep they are sunken by injecting viscous materials with a special piston into the concrete [10]. These studies only studied how accelerated corrosion impacts the binding between coated and uncoated steel bars and concrete. Epoxy, with such a zinc-rich composition, made up the bar coating. There were created six concrete mixtures. Three mixes had 0.4 water-cement ratios and 300, 400, and 500 kg/m^3 of cement contents. In the remaining mixes, 10% weight replacement silica fume was used instead of cement, and the water-to-binder ratio was adjusted to 0.5. Concrete cylinders were used to contain the reinforcing bars. The samples were exposed to a 5V DC flow through a portable power supply for 7 days while still being submerged in a 5% NaCl solution after 3 days of curing. Several tests were performed, including the accelerated corrosion test (ACT), pull-out tests, compressive strength, and weight loss. So, the bond strength and mass loss were reduced for coated bars, among many other important outcomes. Furthermore, there have been fewer, longer, and wider cracks, which indicates that coating reduces the corrosive attack on the steel bars [11,12]. Elbusaefi et al. [13] conducted a comprehensive experimental study involving 200mm cube test specimens. These specimens were immersed in a saline solution (3.5% NaCl) for various exposure periods (3, 7, 10, 14, and 20 days). An external current of 10 mA was applied between the reinforcing steel and a stainless-steel counter electrode. The focus was on assessing the bond strength between the concrete and steel reinforcement. A relative gas permeability test was employed using cylindrical specimens with a diameter and length of 100mm each to analyze the concrete's permeability coefficients. These specimens were thoroughly oven-dried at 105°C before the permeability calculation. Elbusaefi's research highlighted the concrete properties' influence on bond strength. The bond strength of corrosion-damaged specimens varied across concrete types due to differing microstructures and corrosion levels. Intriguingly, a decline in binding strength was observed after the corrosion level surpassed 1.74%. As the corrosion period of the reinforced concrete extended, this decline in bond strength continued. This research also underscores the growing interest in using alternative cementitious materials (SCMs), e.g., fly ash, ground granulated blast-furnace slag, silica fume, and metakaolin. These SCMs have raised curiosity due to their potential impact on the bond strength of steel bars in reinforced concrete.

1.1 Research Objectives

Corrosion in steel bars inside reinforced concrete members can cause severe damage to the entire building. Researchers have sought solutions to reduce steel corrosion in concrete for decades. Any harm or cracks in the effective area used to cover the bars lead to the possibility of steel rusting. Therefore, the main purpose of this research is to reduce the effect of water or moisture on the steel reinforcement. In addition, the effect of adding Styrene-butadiene rubber (SBR) in the concrete mixture as a water ratio was also studied and analyzed.

2.EXPERIMENTAL PROGRAM

2.1. Properties of Materials

2.1.1. Cement

The cement utilized in this experimental study is Ordinary Portland Cement. (O.P.C) made locally in Iraq by Mass Group Holding in (Sulaymaniyah, Iraq). To investigate the cement properties, cement samples were tested in Tikrit University – Chemical Department Lab and then analyzed to tabulate the chemical and physical properties, as shown in Table 1. The results were compared with the Iraqi standard for ordinary Portland cement [14].

Table 1 Chemical and Physical Properties for Cement.

Oxides Composition	Content%	Limit of Iraqi Specification No. 5/1984
Ca O	60.50	-
Al_2O_3	4.70	8% Max
Si O_2	20.13	21 % Max
Fe_2O_3	3.65	5 % Max
Mg O	4.2	5 % Max
SO_3	2.35	2.5 % Max
Loss on Ignition. (L.O.I)	2.75	4 % Max
Insoluble Material	1.36	1.5 % Max
Lime Saturation Factor (L.S.F)	0.92	(0.66 - 1.02)
Physical properties of cement	**Resulting**	**Limit for Iraqi Specification No. 5. / 1984**
Specific Surface area (Blaine method), (m2/kg)	312	(230 m2/kg) lower limit
Setting time (vacate apparatus)		
Initial time setting, (hrs: min)	2hr: 18min	Not less than 45min
Final time setting, (hrs: min)	4hr: 12min	Not less than 10hrs
Compression Strength. (kg/cm2)		
3-day(Duration)	295	Not less than 150.0 kg/cm2
7-day(Duration)	347	Not less than 230.0 kg/cm2

2.1.2. Fine Aggregates

River sand is the type of fine aggregate used in the present research. Sands were gathered from Baiji-Saladin -Iraq. The results from the sieve analysis are arranged in Table 2.

Table 2 Fine Aggregates Sieve Analysis Results

Sieve size	Cumulative Passing (%)	Limit for IQS No.45/1984. (Zone No.2)
9.5mm	100	100 %
4.75mm	100	90 - 100 %
2.36mm	81	75 - 100 %
1.18 mm	67.6	55 - 90 %
600 micron	54.8	35 - 59 %
300 micron	24.7	10 - 30 %
150 micron	4.7	0 - 10 %
75 micron	1.1	0 - 5 %
Pan	0	0

2.1.3. Coarse Aggregate

The coarse aggregate represents the largest portion of the concrete mixture. The workability of the concrete depends on many factors, such as the maximum coarse aggregate size. Crushed river coarse aggregate was selected with the biggest size of 12.5 mm for this research. Before used in the concrete, the coarse aggregate was washed to remove any undesirable materials, such as dust. The results from the laboratory test performed at Tikrit University – Civil & Environment Department are shown in Table 3.

Table 3 Coarse Aggregates Sieve Analysis Results.

Sieve Size	Cumulative Passing (%)	Iraqi's Classification (No.45. /1984)
53 mm	100	100 %
37.5 mm	100	95 – 100 %
9.5 mm	30.1	10 – 40 %
5 mm	0.3	0 – 5 %
2.36 mm	0	0

2.1.4. Mix Water

Tap water supplied from Tikrit was used in the mixture and concrete treatment after the samples were stored at room temperature for 28 days.

2.1.5. Steel Reinforcement

8 mm steel bar diameter was designed to be the main reinforcement in this experimental work, and 6 mm steel bar as stirrups. Table 4 shows the steel properties obtained from Tikrit University – Mechanical Department lab. Three specimens for each diameter were tested, and the average values were considered.

Table 4 Steel bar Test Results.

Bars diameters (mm)	Measured diameter (mm)	Yield stress (f_y) (Mpa)	Ultimate Strength (f_u) (Mpa)	Elongation%
6	6.07	430	568.8	6.1
8	8.12	450	603	7.3

2.1.6.Styrene-Butadiene Rubber (SBR)

Styrene butadiene rubber is a widely used material in different fields. Tire production, isolation dampers, and conveyor belts are examples of using SBR in various branches. In this research, a type of SBR known commercially as Latex L6006 manufactured by EOC Polymers nv Belgium was added to the mix. This material can improve concrete durability due to its excellent properties, such as abrasion resistance. The typical Latex properties are listed in Table 5, while the typical polymer properties are shown in Table 6. Both values in Tables 5 and 6 are provided by the manufacturers.

Table 5 Styrene Butadiene Rubber (SBR - EOC Polymers nv Belgium) Properties.

Typical SBR Properties	
Total solids	48 %
pH	9
Brookfield viscosity (RVT #1/10 rpm)	<300 cps
Surface tension	38 dyne/cm
Minimum film forming temperature	+/- 5 oC.
Density	1.010 kg/l
Calcium (Ca2+) Compatibility	Perfect
Aluminum (Al3+) Compatibility	Perfect
Solvents	Not present
Defoamer	Added
Antioxidant	Added
Bactericide	Added

Table 6 Polymer Properties.

Typical Polymer Properties	
Tensile strength at 20% elongation	2 N/mm2
Tensile strength at break	4.5 N/mm2
Elongation at break	500 %
UV Resistance (7 days at 60 oC)	Poor-need for special Antioxidant
Solubility in Toluene	15 %

2.2. Concrete Mix

The concrete target strength was 22 MPa, and the mix proportions were selected according to ACI 211.1-91 guidelines for normal-strength concrete [15]. The chosen concrete mixture has all the major materials described above and shown in Table 7.

Table 7 Concrete Mix Design.

Ingredient	Cement	Sand	Gravel	Water	W/C ratio
Quantities (kg/m^3)	378.88	797	910	171.69	0.453

As a comparison between two concrete mixes with different water ratios, Table 8 shows that using additive material reduced the amount of water by half.

Table 8 Two Mixes Comparison.

Mortar without Latex	Cement	1
	Sand	3
	Water	0.5
Modified mortar	Cement	1
	Sand	3
	L6006	0.22
	Water	0.25

2.3. Casting and Treatment

2.3.1. Molds

Plastic pipes were utilized as molds to cast the concrete. Each pipe was cut longitudinally into two halves, with a length of 1000 mm and a diameter of 150 mm. The steel disc was welded on a steel plate to be the base of the column mold. Three steel ring clamps were put in the plastic mold's top, mid, and bottom using a plastic sheet to tie and prevent mix water from leaving through the mold groove. Fig. 1 shows the parts used in the concrete pipe form.

Fig.1 Concrete Mold.

2.3.2. Steel Bar Details

This research used Six major steel bars with a diameter of 8mm and a length of 950mm. In addition, 6 mm diameter bars were hooked with 250mm length and spacing of 100mm to use as stirrups. The concrete cover was 30mm. To connect the samples with electric power, a copper electric wire was soldered to the steel bar, as in Fig. 2.

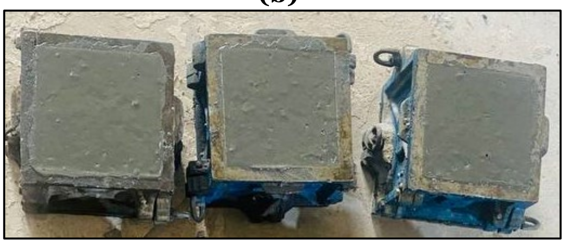
Fig. 2 Steel Bars Connected with Copper Wire.

2.4. Concrete Mixture

An electric concrete mixer capacity of 110kg and speed of 25.5r/min was used to mix the concrete materials. To ensure all the concrete composition was homogenous, a concrete vibrating table was used. Slump test code (ASTM C 143) was taken for each mix, and three standard cubic specimens of concrete with dimensions of 150mm×150mm×150mm were prepared to find the concrete compressive strength, Fig. 3. After casting the concrete, all the samples were covered for curing and to maintain the concrete water. After 28 days, the samples were connected to the accelerated corrosion cells designed to measure the amount of corrosion through the current flown between the steel bar and an electrolyte.

(a)

(b)



(c)

Fig. 3 (a) Slump Test, (b) Specimen on Vibrating Table, and (c) Cubic Specimens.

2.5. Accelerated Corrosion Cells

The accelerated corrosion cells contain a tank with dimensions of (2000mm x 1500mm x 700mm). Seven stainless steel sheets of dimension (200mm x 1000mm) were put at the bottom of the tank. Fig. 4 shows a diagram of a cell accelerator used in this study. To isolate the sheets from the tank base, wood joists were laid under the stainless-steel sheets, which were connected to the negative pole of the power supply device, as shown in Fig. 5. The sheets work as an ion reducer. In addition, wood joists were also laid above the sheets, and the tested columns were put above the wood. To raise the ion, the columns were connected to the positive pole and then submerged in tanks filled with water. After that, chloride of 5% of water weight was added to the water in the tank. Moreover, to increase the dissolved oxygen in the water, a pump was used to cycle the water.

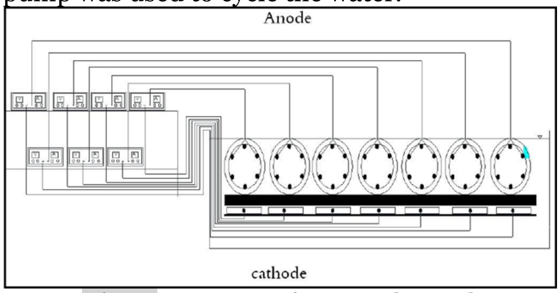


Fig. 4 Diagram of an Accelerated Erosion Cell.

Fig. 5 Corrosion Tank.

2.6. Accelerated Concrete Corrosion

Using a closed circuit through the steel bars can decrease the corrosion time. Therefore, the bars in columns, the Anode, were connected in a parallel circuit to the positive pole, while the stainless sheets, the cathode, were connected in a parallel circuit to the negative pole. Based on previous studies [16], providing oxygen through a water pump using a dense air current, 0.6 mA/cm^2, can increase the corrosion time observed three hours after the process begins. After twenty days, when the columns were removed from the tank, the outermost layer of steel corrosion was covered on the columns' surfaces, as shown in Fig. 6.

Fig. 6 Corrosion Processing.

3. EXPERIMENTAL TESTS

Various concrete tests were conducted to find the workability of fresh concrete mixture, compressive strength, and split strength. In addition, some special tests were done to examine the oxygen concentration, salinity, porosity, and concrete density.

3.1. Slump Test

Slump test was done for each mixture; the results are shown in Table 9. Notice that the mixture with (4%) SBR was very adhesive and cannot perform a slump test.

Table 9 Results of the Concrete Mix Slump.

No.	Addition rate%	Slump test (mm)
1	0	120
2	1	100
3	2	90
4	3	60
5	4	It wasn't possible to do the test
6	5	It wasn't possible to do the test
7	6	It wasn't possible to do the test

3.2. Compressive Strength

The compressive strength of the concrete used (Compressive strength test code C39) in this research was determined by concrete cube and cylinder tests. The results are shown in Table 10. Fig. 7 illustrates the relationship between the compressive load and the displacement.

Table 10 Results of the Compression Test of Concrete Cubes.

No.	Addition rate%	Maximum load (KN) Sample 1	Sample 2	Sample 3	Avg.	Compressive Strength (Mpa) fc_{cu} *	Compressive Strength (Mpa) fc_{cy} **
1	0	530.50	347.60	764.32	547.47	24.33	19.46
2	1	784.57	676.12	676.12	712.27	31.65	25.32
3	2	666.22	758.70	706.27	710.40	31.57	25.25
4	3	776.92	756.22	737.32	756.82	33.63	26.90
5	4	713.70	776.70	830.02	773.47	34.37	27.50
6	5	909.765	671.17	784.57	788.50	35.04	28.03
7	6	755.55	843.30	840.60	813.15	36.14	28.91

* Compressive Strength of Concrete-Cube Test
** Compressive Strength of Concrete-Cylinder Test

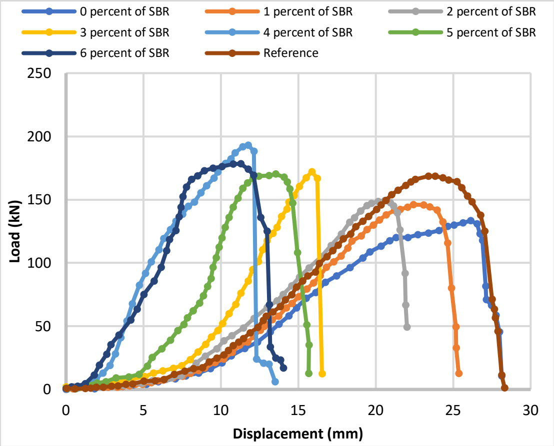


Fig. 7 Relationship Between Compression and Displacement.

3.3. Split Strength

The spilt strength of the concrete can be determined by the cylinder specimen. Through the split test, a concrete tensile strength can be determined. The results in Table 11 show the tensile strength obtained from the Split strength test code (ASTM C496); see Fig. 8.

Table 11 Results of Split Test.

No.	Addition Rate%	Maximum Load (KN)	Tensile Strength (Mpa)
1	0	209.93	2.97
2	1	212.76	3.01
3	2	250.22	3.54
4	3	264.36	3.74
5	4	266.48	3.77
6	5	267.19	3.78
7	6	283.45	4.01

Fig. 8 Concrete Split Test.

3.4. Absorption, Density and Porosity

An additional Absorption test code (ASTM D570) was used to calculate the absorption ratio, calculated density for density test for concrete code in ASTM (C642), and the voids ratio for porosity test for concrete code in ASTM (ASTM D7063). Table 12 shows the results of ten specimens.

Table 12 Results of the Porosity, Absorption, and Density Tests.

No.	Addition Rate%	Absorption rate%	Dry density (gr/mm³)	Wet density (gr/mm³)	Apparent specific gravity (gr/mm³)	Voids ratio
1	0	3.98	0.0019	0.0019	0.0018	0.0070
2	1	3.69	0.0018	0.0019	0.0018	0.0068
3	2	3.45	0.0017	0.0018	0.0018	0.0062
4	3	3.44	0.0017	0.0018	0.0017	0.0062
5	4	3.39	0.0017	0.0018	0.0017	0.0059
6	5	3.29	0.0017	0.0018	0.0017	0.0056
7	6	3.05	0.00118	0.0012	0.00119	0.0038

4. RESULTS AND DISCUSSION

4.1. Compressive Strength

One of the most significant parameters related to the mechanical properties of the concrete is the compressive strength. In this study, SBR was added to the concrete, and standard samples were prepared to investigate the effect of the additive material on this important parameter. The results in Table 10 showed that the reference sample without any SBR in its mixture material had the lowest compressive strength compared with samples having SBR. Also, Fig.7 illustrates the relationship between compression and displacement. It can be seen that about a thirty-one percent increase ratio in compressive strength when one percent of SBR was added to the mix. Furthermore, adding SBR slightly increased the strength between one percent and six percent. This finding was corresponding with the previous study by Jameel [2].

4.2. Steel Weight Losing

Due to the corrosion, steel bars lost weight. The losing ratio was calculated after the column compression test. Main steel bars and stirrups were removed from concrete debris and cleaned, and then each piece was put in an accurate weight machine (0.0001 gram), Fig.9. Clearly, the results from Table 13 show that without SBR addition can lead to loss of more than half of the steel weight, especially for the small size of the bar. However, adding SBR as a ratio of the water can reduce the corrosion and steel weight loss.

Table 13 Loss Ratio of Steel Reinforcement Due to Corrosion.

SBR%	0	1	2	3	4	5	6	R
Ø8weight loss%	19.07	18.88	18.50	18.20	18.04	14.05	13.29	0.00
Ø6weight loss%	52.66	30.66	29.19	28.11	26.37	25.50	25.39	0.00

Fig. 9 Steel Bars Weighting.

4.3 Compression Test for Columns

To investigate the column strength after adding SBR into the concrete mix, concrete column compression tests were done, as shown in Fig. 10. Table 14 shows the compressive strength of the columns and the percentage of adding SBR. Column strength can be improved by adding SBR up to (32) percent with 6% of SBR in the mix.

Table 14 Compressive Strength of the Columns and the Percentage of Adding SBR.

SBR%	0	1	2	3	4	5	6	R
Load kN	133.34	146.1	149.5	172.1	193.1	170.2	176.3	168.5
Type of Failure	Crushing (Compression Failure)							

Fig. 10 Column Compression Test.

5. CONCLUSIONS

From the obtained results, the following important points can be concluded:

1- Adding SBR to the concrete mixture improves the compressive strength, especially with a small replacing ratio. The most significant increasing ratio in the strength was about thirty percent, with just one percent of SBR. In addition, when the voids ratio decreased with increasing SBR value, the compressive strength increased positively.

2- Results show a decrease in slump value with increasing SBR amount up to four percent. After adding five percent or more of SBR, the fresh concrete workability worsened, which may be explained as follows: by increasing the SBR ratio, more water was required for SBR to cover its surface, leading to less free water in the mixture.

3- Corrosion reduced the steel bar strength by losing the cross-sectional area and steel weight. In this study, results showed that existing SBR in the concrete decreased the steel bars' corrosion by about fifty percent for the small size of the bars.

4- Using SBR in structural members was part of this study. The columns' compressive strength increased loading capacity when SBR was added to the concrete.

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