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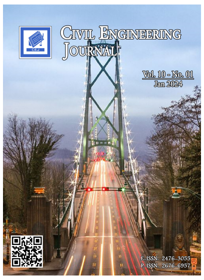

Experimental investigations: Reinforced Concrete Beams Bending Strength with Brine Wastewater in Short Age

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Abstract

The scarcity of waste in some regions has led to the contemplation of other approaches to providing potable water for human use. In the present research, it is proposed that a portion of the brine wastewater be recycled for potable water purposes through its incorporation into concrete and reinforced concrete compositions. The researchers performed an extensive empirical investigation to examine the impact of incorporating brine wastewater into the concrete mixture on the shear strength, bending stress, and compressive strength of the material. A total of seventy-two beams, each measuring 500 mm in length, 100 mm in width, and 100 mm in depth, were observed. A total of twelve beams were designated as control specimens, while an additional sixty beams were subjected to immersion in brine wastewater at varying concentrations of 2.5, 5, 7.5, 10, and 15%. The beams were reinforced using two longitudinal steel bars with a diameter of 8 millimeters in the tension zone and 6 millimeters in the compression zone. The stirrups included in the study were also measured to have a diameter of 4 mm. The samples were examined at intervals of seven, fourteen, twenty-one, and twenty-eight days. Based on the findings of this study and other relevant studies, it was determined that the use of 10% fresh water as a substitute for brine wastewater yielded the most optimal outcomes. The results obtained after a duration of 28 days indicate a notable increase in both the compressive and bending strengths of the concrete samples, with improvements of around 22% and 2.6% seen in comparison to the reference specimens. The impact of brine wastewater on the corrosion of reinforcing steel in reinforced concrete was investigated. The empirical findings indicated that the introduction of brine wastewater at a concentration of 10% to the concrete constituents did not provide any discernible repercussions over a period of 65 days.

Keywords: Bending Strength; Brine Wastewater; Reinforced Concrete Beams; Compressive Strength.

1. Introduction

After experimenting with a wide variety of materials, manufacturers of concrete and reinforced concrete were able to refine their processes and product offerings to meet a wide variety of needs [1–3]. From an economic and environmental standpoint, waste creation and disposal is an issue of fundamental relevance for growth at the present moment, with direct consequences for sustainability [4–6]. To ensure that the concrete's resistance strength is not compromised, it is important to pay close attention to the ratios of its components while recycling materials into the material [7–9]. Previous research has shown this [10–12]. Until today, the most significant reinforcing element in reinforced concrete is rebar, which remains an addition to glass and polymer, although in a smaller amount [13–15]. Despite several trials using plastics and the byproducts of agricultural processes, this remains the case [16, 17]. About a billion tons of water are used in the production and curing of concrete and reinforced concrete, which is a major threat to the world's freshwater supplies and particularly to the Hashemite Kingdom of Jordan, which is one of the world's poorest nations in this regard. Brine wastewater was recommended as an option as a result [18–20].

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Tensile reinforcements, such as rebar or mineral fibers, are utilized in bending-prone areas of a structure to avoid collapse and boost resistance strength [21]. Corrosion of the rebar in bending-prone reinforced concrete elements is a constant source of concern as structures age [22, 23]. Based on responses, it has been determined that erosion increases at first, and the strength of the resistance to flexion increases and then decreases, and here it depends on the concrete coating layer for the rebar. Erosion of rebar increases the resistance to bending in reinforced concrete by a factor of two [24, 25]. Since brine wastewater contains components that can affect the bonding strength and erosion of iron, this topic was carefully studied, and it was found that brine wastewaters have little effect on the shortage. The corrosion of rebar and bonding strength play a key role in the decrease in the strength of the resistance of reinforced concrete in general and the strength of bending. [8, 10].

When placed in a saline and natural environment, where they were exposed to sunlight and salt water, it was discovered that the bearing capacity of reinforced concrete beams reinforced with polymer sheets reinforced with carbon fibers is 67% greater than the normal samples. It is challenging to build optimum reinforced concrete beams using the conventional technique due to constraints imposed by the reinforced ratio and dimensions of beams produced with the same strength [26–28]. This also pushes us to employ brine water in the manufacturing of reinforced concrete.

The aim of this research is of great economic and environmental importance to understand the impact of using brine wastewater in the production of concrete and reinforced concrete, as well as the important properties of the concrete and reinforced concrete that are affected by the substitution of brine wastewater for regular water in the production process, such as bending strength, compressive strength, the weight of concrete, and other properties. Using the apparatus presented in the result and a well-established equation, we were able to determine the flexural strength:

$$Strength\ of\ Flexural = PL / BD^2 \tag{1}$$

where, P is Failure load (KN), L is Effective span length (mm), B is Beamwidth (mm), D is height (mm).

2. Methods and Materials

2.1. Wastewater of Brine, Cement, and Silica Sand

Specifications, Chemical, and physical parameters can be found in the previous studies [6-9].

2.2. Reinforcement of Steel

The process of the sample's reinforcement is as follows: In the tension zone, steel diameter 8 was used, and in the compressive zone diameter 6, and the stirrups diameter 4 (Figures 1 and 2).

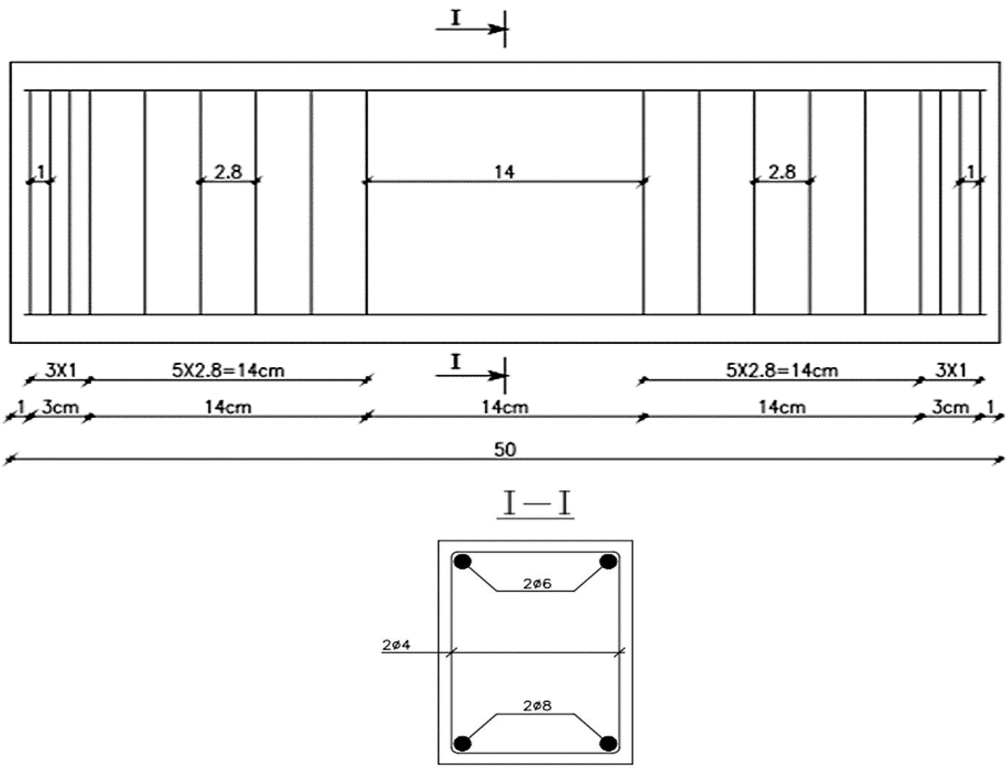

Figure 1. Test Beams Designs of Bending

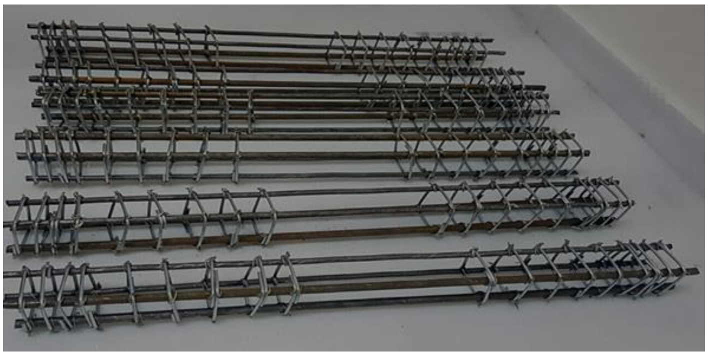

Figure 2. The Shape of the Reinforcement of Bending

2.3. Reinforced Concrete Beams Test Investigations

To precisely determine the compressive strength of every ratio and the used reference mixture, three measurement cubes with dimensions of 150×150×150 mm were obtained from the same mixture for each set of beams, for a total of seventy-two beams. Twelve reference samples were made without brine wastewater, and sixty samples of brine wastewater included three samples from each added percentage of 2.5, 5.0, 7.5, 10.0, and 15.0% (Figure 3). The findings of the tests performed on all samples at 7, 14, 21, and 28 days are shown in Tables 1 and 2.

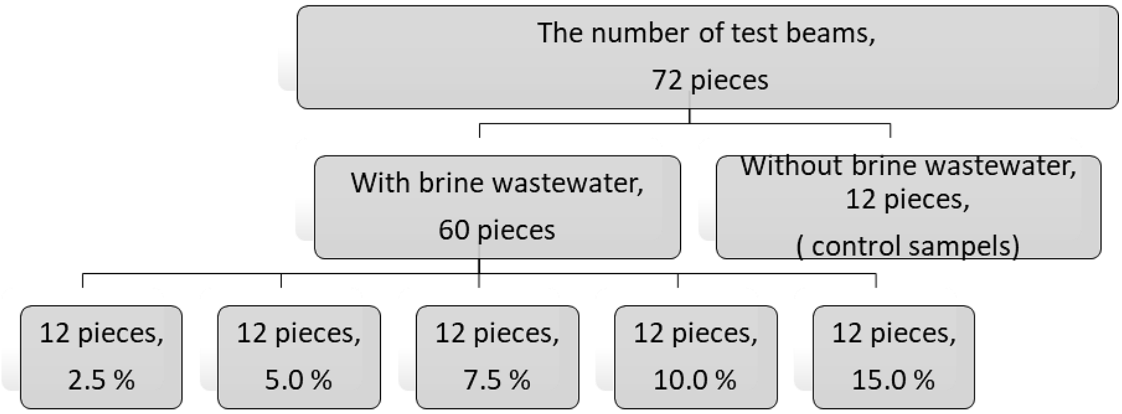

Figure 3. The Program of the Reinforced Concrete Beams Test Investigations

Table 1. Strength of Compressive of Concrete with Wastewater of Brine

Age (days)	Series	Cubes	Cubes of (cm) 15×15×15	Average loads (stress in MPa)					
				Control samples	Cubes with brine wastewater				
					2.5%	5.0%	7.5%	10.0%	15.0 %
7	I	1	C.c.-1 / C.b.-1	21.75	23.13	23.75	24.33	25.02	20.31
		2	C.c.-2 / C.b.-2						
		3	C.c.-3 / C.b.-3						
14	II	1	C.c.-1 / C.b.-1	25.38	25.95	26.38	27.15	28.01	23.38
		2	C.c.-2 / C.b.-2						
		3	C.c.-3 / C.b.-3						
21	III	1	C.c.-1 / C.b.-1	28.27	29.55	30.28	31.45	33.82	26.55
		2	C.c.-2 / C.b.-2						
		3	C.c.-3 / C.b.-3						
28	IV	1	C.c.-1 / C.b.-1	29.32	32.02	33.37	33.72	35.85	28.34
		2	C.c.-2 / C.b.-2						
		3	C.c.-3 / C.b.-3						

C.c. - Cubes without brine wastewaters (control samples).

$C_{.b.}$- Cubes with brine wastewater.

Table 2. The Reinforced Concrete Bending Strength with Wastewater Containing Brine

The Age (days)	Series	Beams	Beams (cm) 10×10×50	Average loads (stress in MPa)					
				Control samples	Beams with brine wastewater				
					2.5%	5.0%	7.5%	10.0%	15.0 %
		1	Bc-1 / Bb-1						
7	I	2	Bc-2 / Bb-2	5.53	5.43	5.6	5.74	5.93	5.02
		3	Bc-3 / Bb-3						
		1	Bc-1 / Bb-1						
14	II	2	Bc-2 / Bb-2	6.17	5.99	6.27	6.40	6.50	5.50
		3	Bc-3 / Bb-3						
		1	Bc-1 / Bb-1						
21	III	2	Bc-2 / Bb-2	6.45	6.26	6.67	6.80	6.91	5.77
		3	Bc-3 / Bb-3						
		1	Bc-1 / Bb-1						
28	IV	2	Bc-2 / Bb-2	7.26	6.51	7.20	7.28	7.45	6.09
		3	Bc-3 / Bb-3						

Bc – Beams without brine wastewater (control samples).

Bb - Beams with brine wastewater.

2.4. Work of Laboratory

This study included the following four laboratory experiments: The first step is to cast a concrete mixture over the reinforcement to completely cover it. In the second step, the model is molded, the surface is polished, and it is cured. Third, when using reinforcement concrete reference mixes, fortify the bond between the reinforcement and concrete. Fourth, the concentration of the brine wastewater is changed by adding varied quantities of regular water. The goal of this procedure is to replace part of the regular water supply. The building lab at Ajloun National University served as the site for all the tests. Laboratory procedures are shown in Figures 2 and 4 to 7.

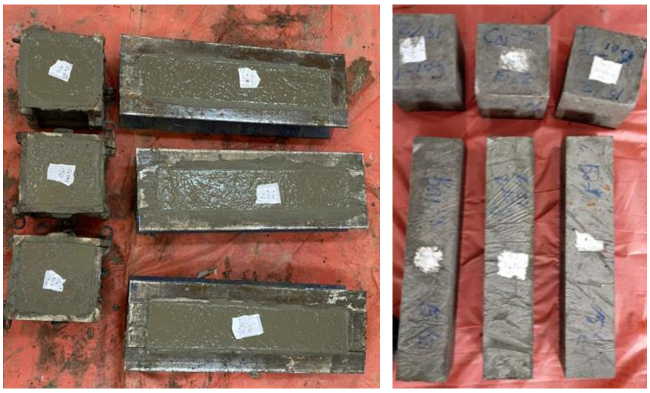

Figure 4. The Shape of the Beams and Cubes

Figure 5. Nylon was used to cover the specimens in this study

Figure 6. Curing Process

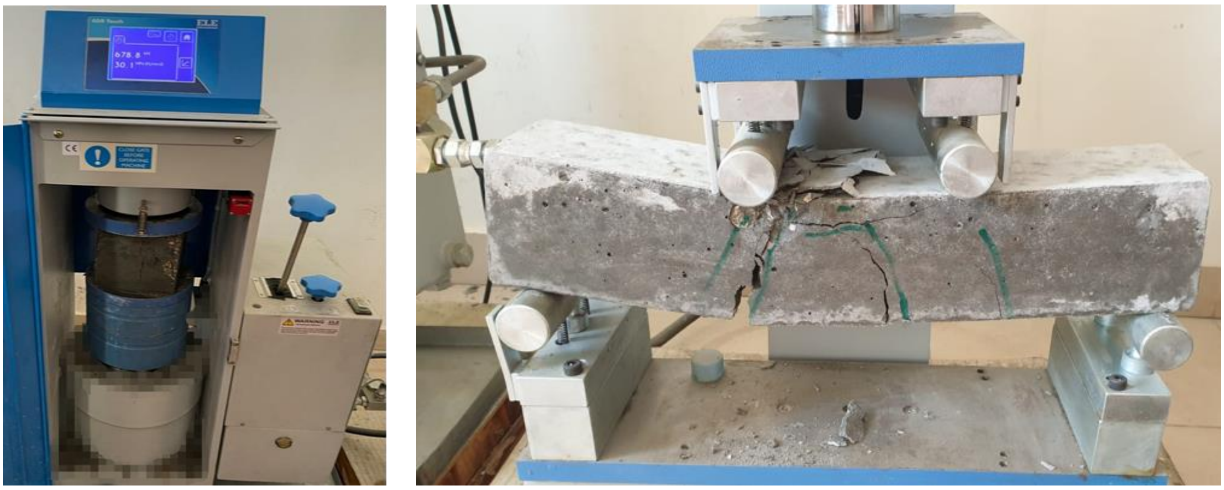

Figure 7. Sample Screening Device of Concrete and Reinforcement Concrete in Compression and Bending

2.5. Bending and Compressive Strength Test

cubes with dimensions of 15×15×15 cm, and beams with dimensions 100×100×500 mm were used to check compressive and flexural strength According to British specifications (BS.1981.PART (118): 1983), And by using device used scan capacity 2000 KN/450000 lbs., ADR Touch 2000 Semi-Automatic Compression Machine with Digital Readout the code: 363090/01 (Figure7).

Table 1 to 7 shows the average results obtained from laboratory work for all mixtures and ages.

Table 3. Steel Reinforcement Test Results Studied for This Research

Diameter, D (mm)	Number of samples	Length, mm	Tensile Force, (KN)	Average tensile Force, (KN)
	1	488	16.25	
6	2	487	16.20	16.22
	3	490	16.22	
	1	489	23.7	
8	2	491	24.1	23.90
	3	495	23.9	
	1	489	44.62	
10	2	488	44.48	44.50
	3	480	44.39	

Table 4. The Tensile Strength of Steel Reinforcement after Immersion in Normal Water With 10 % Brine Wastewater Added

Diameter *Φ* (mm)	Number of samples	Grade	Length (mm)	Weight (g)	Average tension Force (KN)	
					Before	After
	1		493.50	308.61		
10	2	40	505.10	309.60	44.56	42.18
	3		502.00	315.30		
	1		478.00	159.10		
8	2	40	489.00	162.70	20.98	20.29
	3		490.00	165.20		
	1		478.00	87.20		
6	2	40	475.00	86.50	16.20	15.71
	3		480.00	88.10		

Table 5. Presents the data on the tensile strength of the steel reinforcement after its utilization in reinforced concrete structures exposed to 10% brine wastewater

Diameter (mm)	Number of samples	Grade	Length (mm)	Weight (g)	Average tension Force (KN)	
					Before	After
	1		480.00	308.62		
*Φ*10	2	40	480.20	309.64	44.23	43.75
	3		480.10	308.61		
	1		606.20	105.10		
Φ14	2	60	605.60	104.30	105.4	104.67
	3		608.74	105.6		
	1		505.00	780.9		
*Φ*16	2	60	505.00	780.9	109.8	108.42
	3		500.00	774.80		

Table 6. Concrete Weight with Brine Wastewaters

No.	Percentage Continent (%)	Weight in (grams)	Density (γ) $\times 10^{-4}$
1	0 % (control)	8550	2,533
2	2.5%	8580	2,542
3	5%	8610	2,551
4	7.5%	8645	2,561
5	10%	8675	2,570
6	15%	8745	2,591

Table 7. Workability Concrete with Brine Wastewater

No	Percentage continent	The slump in (cm)	Failure mode
1	0% (control)	5.2	The mixture is normally sold
2	2.5 %	3.8	The mixture is sold
3	5 %	2.8	The mixture is very sold
4	7.5 %	1.7	The mixture is very, very sold
5	10 %	1.6	The mixture is extremely sold
6	15 %	0.9	The mixture is extremely sold

3. Results and Discussion

Following the completion of the laboratory work and the acquisition of test results from Tables 1 to 7, an analysis and discussion of the obtained data is presented below:

3.1. The Effect of Brine Wastewater on Reinforced Steel and Concrete

According to the findings of the laboratory and prior research [6–10], it has been determined that the optimal proportion of brine wastewater that may be included in concrete and reinforced concrete to achieve optimal outcomes is 10%. Therefore, an investigation was conducted to examine the impact of brine wastewater on reinforcing steel in the context of a scarcity.

3.1.1. Reinforcement Steel

Diameters 6, 8, and 10 were immersed in normal water, to which 10% wastewater was added, for 65 days, and a test for tensile strength was performed. Note that we tested the same steel before the experiment, and the results were recorded in Table 4. According to the test results, reinforced steel has lost about 3% of its tensile strength. When testing the strength of bonding between reinforcements of steel and concrete, where a diameter of 10, 14, and 16 was used [8], the steel was examined before the experiment. After the end of the experiment, we tested the steel on tensile strength to see the effect of concrete added to its brine wastewater on the steel, and all the results were recorded in Table 5. Note that the tests were carried out after 35 days.

From Table 4, it was found that there is no short-term effect of brine wastewater added to concrete on reinforcing steel. The simple difference between the tensile strength of steel before and after use is due to the steel tensile strength of concrete before and after second testing, which, to its weakening a little, equals about 1%.

3.1.2. Concrete

To find out the effect of brine wastewaters on concrete, the weight of regular concrete was found and added to it in different proportions of brine wastewater, as indicated in Table 6. Table 6 and Figure 8 show that the weight of concrete is affected directly by the proportion of wastewater of brine added; when this proportion is increased by 10%, the result is a weight greater than the reference value of 1.46%. Table 7 and Figure 9 show that the addition of brine wastewater had a negative impact on the workability of concrete. This was true regardless of the amount of brine wastewater used. Therefore, additives are required to enhance the concrete production procedure.

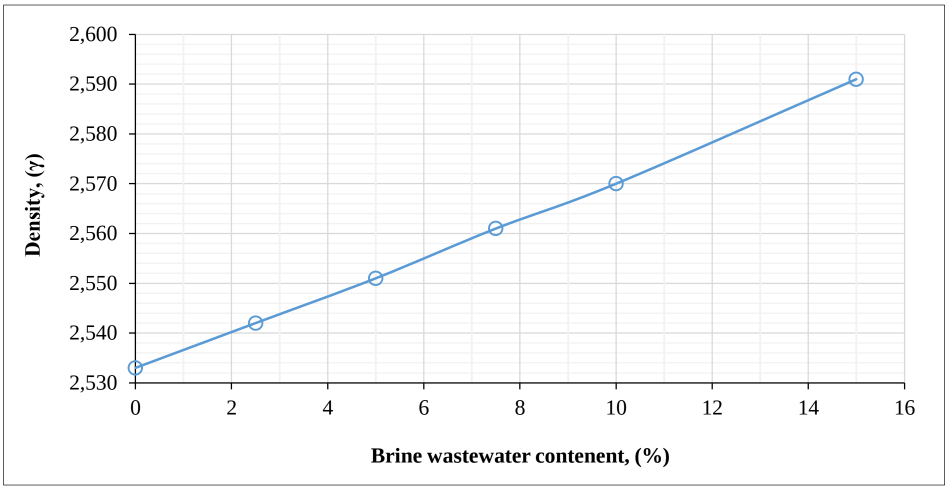

Figure 8. Concrete Weight with Brine Wastewaters

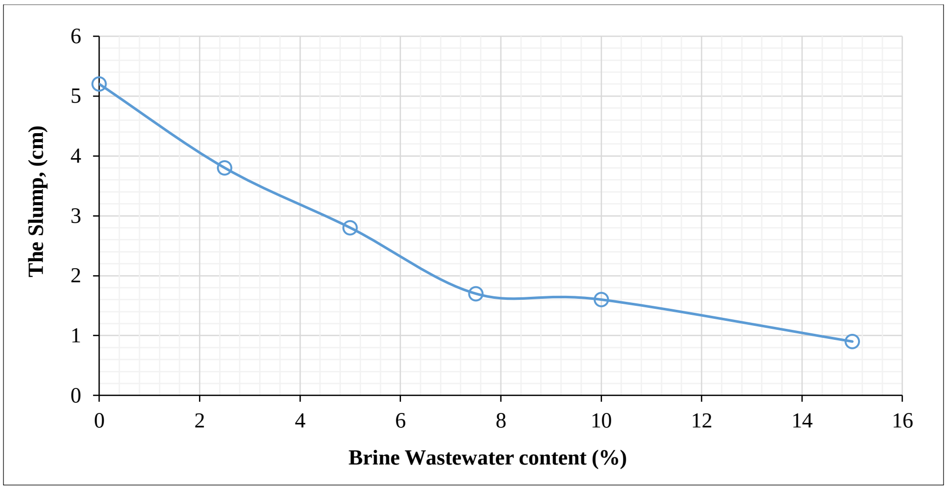

Figure 9. Workability of Concrete with Brine Wastewater

3.2. Strength of Compressive

Compressive concrete's strength may be affected by a number of factors, including cement quantity, age, water-to-cement ratio, brine wastewater-to-cement ratio, additives, and curing procedure. Surface hardness was improved in concrete samples that were combined with brine wastewater as compared to those that were not. It has been shown, without the use of additives to improve the qualities of the concrete mixes, that specimens containing brine wastewater showed reduced workability compared to other mixtures. The breakdown modes shown by the Cube when exposed to saline wastewater (Figure 10) are quite different from those displayed by their more recognized concrete analogues (Figure 11). There was a little swelling after using the cube with brine wastewater, which might be because of the salt. Testing was performed on all samples at 7, 14, 21, and 28-day intervals. Maximum compressive strength from brine wastewater was achieved at a concentration of 10%. After curing for 28 days, the compressive strength reached 35.85 MPa at this concentration. Notably, this value represents a 22% improvement compared to standard concrete (Figure 12 and Table 1).

Figure 10. Illustrates the various failure modes seen in the cubes subjected to brine wastewater

Figure 11. The failure modes of the cubes without brine wastewater, as seen in Figure 11, are presented herein

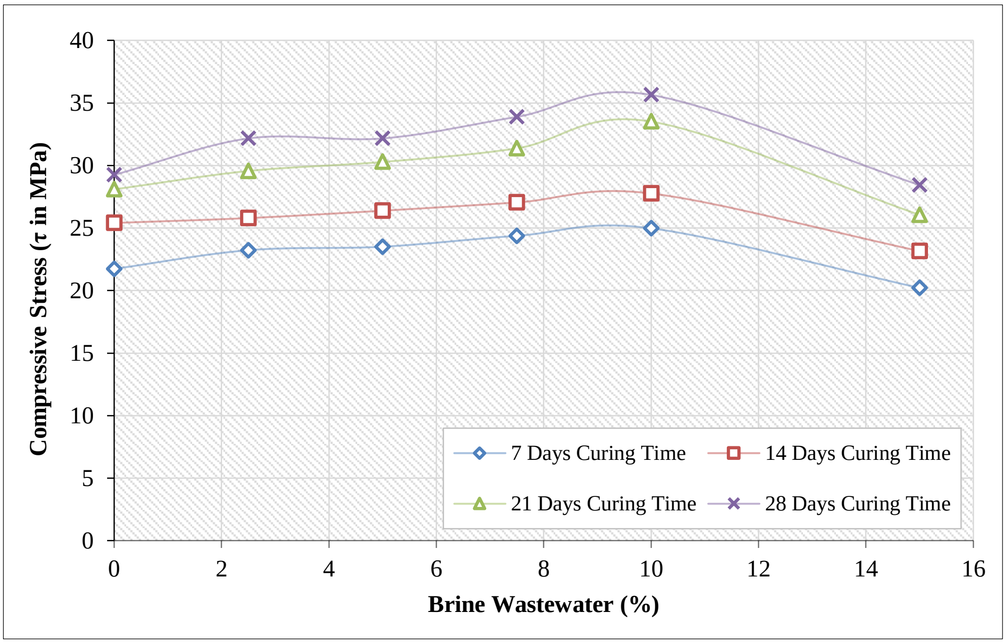

Figure 12. Illustrates the concrete's compressive strength after 7, 14, 21, and 28 days of curing, depending on the percentage of wastewater and brine used

The results showed that the compressive strength of concrete made with brine wastewater ranged from about 9.0% to 22.0% greater than that of concrete made without brine wastewater, depending on the ratio of brine wastewater used. This impact is especially prominent during the first seven-day period, due to the crystallization process assisted by the presence of brine wastewater. However, the observed percentage boost in compressive strength drops below that of conventional concrete by around 3% once the brine wastewater addition rate exceeds 15%. Several studies [6–9] have confirmed the accuracy of this claim. Figure 12 and Table 8 show that the compressive stress curves for concrete aged with the addition of brine wastewater follow the same general pattern as those for conventionally aged concrete.

While there are no historical records of using brine wastewater in concrete mixes to create reinforced concrete, there are a number of comparative studies, including the use of saltwater. The compressive strength of concrete may be improved by using seawater, which is known to have a high proportion of salts [29]. Previous studies' compressive strength indicators are consistent with our own, even if their physical and chemical characteristics are not comparable.

Comparing the results of this study with those of others [6–10] on the topic of compressive strength, we find that they are essentially identical, leading us to the conclusion that concrete to which brine wastewater has been added at a rate of up to 10% has a higher compressive strength than regular concrete.

3.3. Strength of Bending Reinforced Concrete

Several factors affect the bending strength of reinforced concrete. These include the concrete's age, the cement's content and ratio, the brine wastewater to cement ratio, the curing process, the presence of additives, the construction method, the type of reinforcement used, and so on. Despite their superficial resemblance to conventional concrete, the failure mechanisms found in beams exposed to brine wastewater are distinct from those in regular concrete. The angle of the cracks at the point of loading is less of a factor in the brine-exposed samples. The fissures vary in breadth and height but otherwise measure similarly. Figures 13 and 14 show this clearly. It's also important to note that the exposed samples to brine seem lighter in color than the regular samples.

Figure 13. Failure Modes of the Beams with Brine Wastewater

Figure 14. Failure Modes of the Beams without Brine Wastewater

The highest flexural strength of reinforced concrete made using brine wastewater was 7.23 MPa, which is somewhat less than the 7.26 MPa observed in conventional reinforced concrete. The bending strength of reinforced concrete is improved by 2.5% when brine wastewater (at a concentration of 10%) is added to the mix. When compared to regular reinforced concrete, the bending strength drops by 10% and 16% when the ratio is 2.5% or 15.0%. However, when brine wastewater is added at concentrations of 5% and 7.5%, the bending strength approaches that of the standard samples. At the 28-day point, these results become apparent. The bending strength of the material was also shown to diminish after 7-28 days of age when a 2.5% ratio was used. The lack of accessible material for crystallization, which is required to increase bending strength, is to blame for the decline. During the same aging time, the bending strengths of the remaining ratios of 5%, 7.5%, and 10% are either higher than or equivalent to the reference samples. The bending stress curves for reinforced concrete with the introduction of brine wastewater shows a similarity to the curves observed in conventional concrete and reinforced concrete, as illustrated in Figure 15, and Table 2.

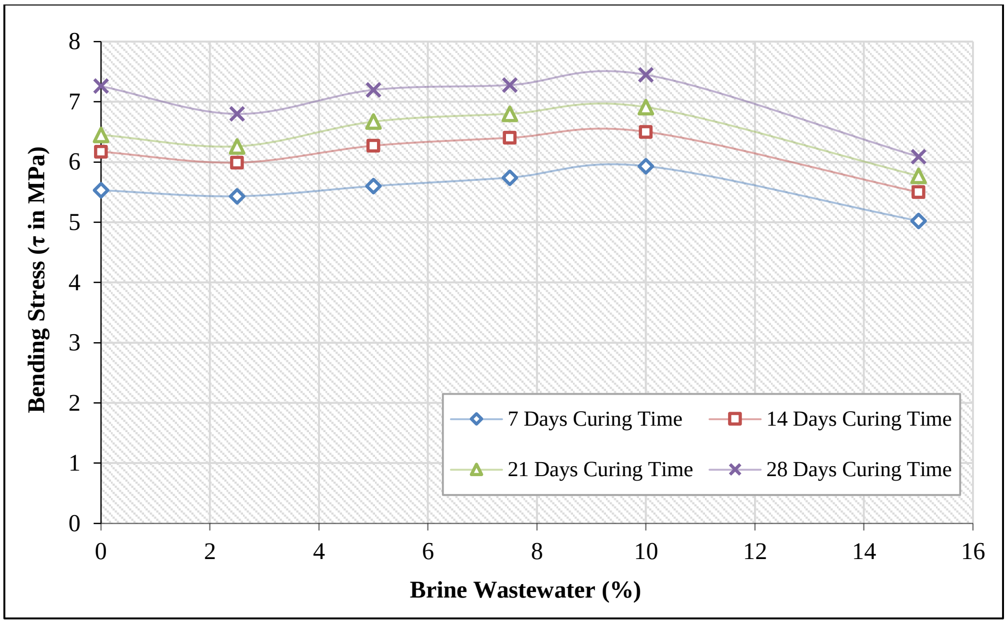

Figure 15. Bending Strength (MPa) of Reinforced Concrete Mixes of Different Percentages of Wastewater of Brine for (7, 14, 21, and 28 Curing Days)

Many studies have been undertaken on the use of treated wastewater, but as we noted before, brine wastewater is not utilized in the construction of reinforced concrete or its flexural testing. There was no decrease in bending strength, and the bending strength increased by 2-5% after adding the aforementioned materials to both piles, even though this water is not identical to brine wastewater in terms of physical and chemical properties.

The *strength reduction factor*, denoted by (Φ), is regarded as a crucial factor in determining safety. It is multiplied by nominal strength to obtain design bending strength (Mn), design shear strength (Vn), design axial load (Pn), and so on for the rest of the strongest types. Coefficient values vary in accordance with code requirements for strength and failure mechanisms (ACI Table 21.2.1). From the Table, it is known that the elements exposed to an axial force or a bending moment or both are regulated by the tensile failure it is ($\Phi = 0.9$), which relates to the tests that we have done in this study. In most cases, the design strength should be greater than or equal to the design forces.

$$Mu \leq \Phi\ Mn \tag{2}$$

This means that the nominal strength must be greater than the required strength by an amount equal (1/Φ) to at least that:

$$\text{Mn} \geq \text{Mu}/\ \Phi \tag{3}$$

From here, the parameter Φ is important when designing. Based on the modest studies that have been carried out so far in this research and research [8, 10] in principle, we can suggest a coefficient of (η) to replace the coefficient of (Φ), this is due to the consideration of the bonding strength between rebar and concrete, to which saline wastewaters are introduced, in addition to the necessary safety. For example, when using reinforced concrete for diameters 6, 8, 10, 12, 14, and 16, it can be taken from [10].

4. Conclusion

The laboratory experiments included the production of concrete and reinforced concrete, including Brine wastewaters. The subsequent analysis focused on evaluating various features of the concrete and comparing the results with reference mixes. Based on these investigations, the following conclusions were drawn: The utilization of brine wastewater as a substitute for a portion of conventional water in the manufacturing process of reinforced concrete presents a viable alternative. In comparison to the reference mixes, the combinations incorporating brine wastewater exhibited higher compressive strength. Moreover, the inclusion of 5.0% to 10% of brine wastewater resulted in increased bending strength of reinforced concrete when compared to standard reinforced concrete. These studies provide evidence that the optimal addition of brine wastewater to the reinforced concrete mixture is 10%. However, it should be noted that the impact of brine wastewater on steel reinforcement is minimal when added up to 10%. It is important to acknowledge that the addition of wastewater to concrete does have an effect, as it increases the weight of the mixture while simultaneously reducing its workability. Based on the findings derived from the laboratory investigation, we propose that more exploration be conducted on the following aspects. It is suggested that a study be conducted to examine the enduring impact of brine wastewater on steel reinforcement. The inclusion of Brine Wastewater has the potential to alter the characteristics of reinforced concrete. Therefore, it is crucial to analyze samples at intervals of 90, 180, 360, and 720 days to assess their influence on the material. Drawing upon the findings of this investigation and previous scholarly works, it is recommended that concrete containing brine wastewater be employed in the construction of road pavements, water fountains, and similar infrastructure projects.

5. Declarations

5.1. Author Contributions

Conceptualization, H.A.A., A.M.S., L.A.A., and B.A.A.; methodology, H.A.A., A.M.S., L.A.A., and B.A.A.; formal analysis, L.A.A.; investigation, H.A.A.; writing—original draft preparation, H.A.A., A.M.S., L.A.A., and B.A.A.; writing—review and editing, H.A.A., A.M.S., L.A.A., and B.A.A. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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