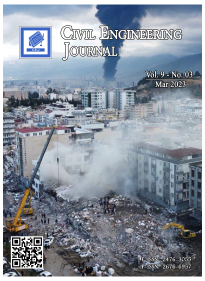
Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 03, March, 2023



Torsional Strength of Reinforced Concrete Beams with Brine and Olive Oil Mill Wastewater

Hamadallah Al-Baijat [1], Husein A. Alzgool [2*]

[1] Department of Civil Engineering, Arab College University of Technology, P.O. Box 926845, Amman, Jordan.

[2] Department of Civil Engineering, Faculty of Engineering, Ajloun National University, Ajloun, Jordan.

Received 22 December 2022; Revised 13 February 2023; Accepted 21 February 2023; Published 01 March 2023

Abstract

The authors conducted a comprehensive research study on adding olive oil mill and brine wastewater to the concrete mix to investigate torsion, bending stress, shear, and compressive strength. The total number of specimens were 33 beams 100 mm (depth) × 100 mm (width) × 500 mm (length). Three beams were used as control samples, and thirty beams were divided into two groups: fifteen samples were from an olive oil mill, and the other fifteen were brine wastewater with different percentages of additive material (olive oil mill and brine wastewater), with 2.5, 5.0, 7.5, 10.0, and 15.0 % of each. The beams were reinforced with 4 ϕ 8 mm as longitudinal steel bars and ϕ 4 mm stirrups spaced at 20 mm. All specimens were tested at 28 days. It was found that the torsional strength of the samples containing brine wastewater when added at the best percentage, which is 10%, was 5.46 MPa. As is the case when adding olive oil mill wastewater with the best percentage, which is 7.5%, it was 5.16 MPa. These data are greater than the torsional strength in the reference samples, which were 4.38 MPa, meaning that the torsional strength when adding brine wastewater and olive oil mill wastewater increases by 24% and 17%, respectively.

Keywords: Torsional Strength; Brine Wastewater; Olive Oil Mill Wastewater; Reinforced Concrete Beams.

1. Introduction

Based on previous studies and the results obtained, it is convincing that it is possible to use olive oil mills and brine wastewater in the production of reinforced concrete. Since the proposed materials are new, they must be well studied on all the basic properties that affect the strength of structural elements such as torsion, bending, compression, and other properties to develop sustainable proposals when designing reinforced concrete structures using the new materials because of their economic and environmental importance.

Previous research showed that the addition of olive oil mill and brine wastewaters significantly increased the compressive strength when compared to the reference mixtures and also showed that the best percentages that could be added were 7.5% and 10% of the olive oil mill and brine wastewater, respectively, which have been proven in this research [1–4].

Based on the continuous technological development for several decades, several researchers were looking for materials for the development of concrete and reinforced concrete because it is considered one of the most important building materials [5-7]. Many materials have been used to strengthen concrete, including plastics, polymers, fiberglass, and other materials [9–12]. The shortage of fresh water in many countries of the world, including Jordan,

* Corresponding author: alzgoolh23@gmail.com

http://dx.doi.org/10.28991/CEJ-2023-09-03-012

due to industrialization in general manufacturing and processing concrete and reinforced concrete, which consumes one billion tons, made us look for new water resources to relieve pressure on freshwater resources [13–16]. So, we have, in this research, suggested two of these low-cost materials (olive oil mill wastewater and brine wastewater). However, the use of the two new materials will significantly reduce freshwater use and environmental effects.

When the torsional properties of ordinary reinforced concrete and high-strength reinforced concrete beams are compared, we find that high-strength reinforced concrete has greater compressive strength and torsional resistance than ordinary reinforced concrete [17–19]. The beams in construction buildings are subject to a torsion moment that affects the design process, and here the ratio and type of rebar play an important role [20–23]. To prevent the torsional collapse of concrete beams, they are usually reinforced with stirrups [24–27].

In this research, the authors conducted a comprehensive study on torsion, compressive strength, bending, and stress in the beam with 33 samples, as shown in Figure 3. The new material was added to the concrete mix to improve its properties: one olive oil mill and brine wastewater as a percentage of regular water (2.5, 5, 7.5, 10, and 15), and compared with reference samples. Since there was not enough research in the literature review about brine and olive oil mill wastewater with a torsional cantilever beam. Throughout the literature review search, it appeared that this study and the previous research were at the top of the list in this field of study. In this research, the authors conducted comprehensive research to investigate the study of the torsional moment, compression strength, and stresses in the beam. The new two materials were added to the mix, which was brine and olive oil mill wastewater with 2.5, 5, 7.5, 10, and 15 was replaced with fresh water. The results showed that the torsional moment increased by 8.2%, 13.4%, 16.4%, 24.6%, and 17.8% for brine at the percentages of 2.5, 5, 7.5, 10, and 15. The olive oil mill wastewater study showed the torsional moment also increased by 5.48%, 8.2%, 17.8%, 16%, and (-5.48%). It was found that for both brine and olive oil mill wastewater, the acceptable percent of new materials was 7.5%, and 10% was replaced by regular water.

2. Materials and Methods

The authors suggested building a device to conduct a torsional investigation on cantilever concrete beams. The device was prepared from L 5×5×1/2 cm, forming a square 102×102 mm attached to the wall in the laboratory. This square frame is fixed well with anchorage bolts to the wall (point B). The concrete beam is attached to point B, which provides support at the wall, and the other end (point A) is the free end. Figures 1 and 2 show a square steel frame attached to the free end (101×101 mm) opening with a steel arm 500 mm welded to load W to produce a torsional moment.

$$T = Wd \tag{1}$$

$$\sigma = MC / I \tag{2}$$

$$M = W\,(AB) \tag{3}$$

where T is torque, W is load, d is Distance, σ is Stress, M is Bending Moment, I is Moment of Inertia, C is h/2, the height of cross-section.

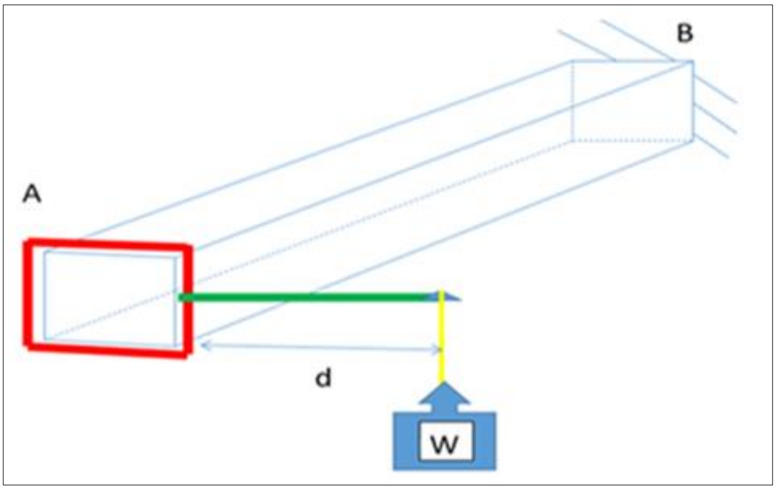


Figure 1. Concrete Cantilever Reinforced Beam Subject to Torsional, Shear, and Moment

Figure 2. The Build-up Specimen is Fixed at the Wall and Free at the End, With the load Attached to the End of the Arm

The objective of this research is to study the effect of the olive oil mill and brine wastewater on the following:

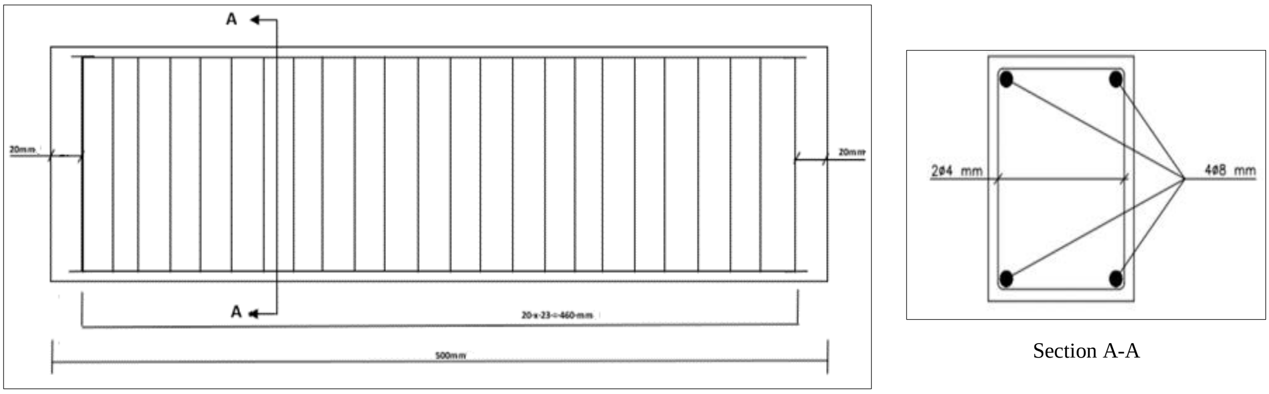
- Torsional strength of reinforced concrete beams and compare it with the reference samples, due to the economic and environmental importance of this topic;
- Compressive strength f_c' of concrete;
- Flexural strength;
- Stress due to bending.

2.1. Brine Wastewater, Cement, Olive Oil Mill Wastewater, and Silica Sand

Specifications, Chemical, and physical properties can be referred to in Alzgool et al. [1], Alshboul et al. [2], and Alzgool [3].

2.2. Steel Reinforcement

The beams were reinforced with 4 ϕ 8 mm diameter bars and ϕ 4 mm stirrups spaced at 20 mm, as shown in Figure 3, and steel Grade 40 according to the ACI code.



Section A-A

Figure 3. Torsion Test Beam Designs

2.3. Reinforced Concrete Beam Test Investigations

The authors conducted 33 beams measuring 100×100×500 mm were made: 3 reference samples without olive oil mill and brine wastewaters and 30 samples divided into 15 with olive oil wastewaters and 15 with brine wastewaters (Figure 4). To know the compressive strength of each ratio and the reference mixture accurately, from the same mixture for each group of beams, three measuring cubes of 150×150×150 mm were taken, and all samples were tested after 28 days.

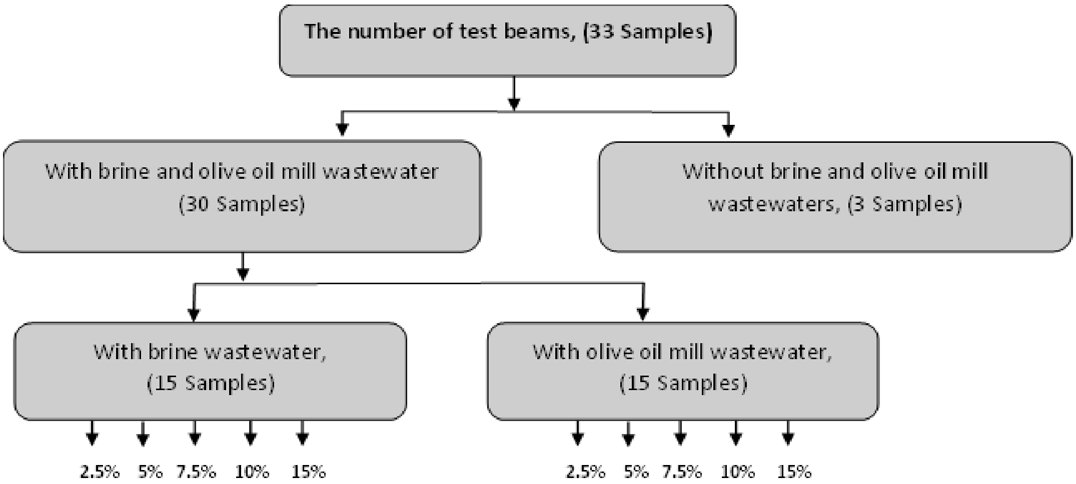


Figure 4. The number of Specimens Represents 3 Beams as a Reference and 30 Beams divided into the Categories of Brine and Olive Oil Mill Wastewater with Varying Percentages of Both

3. Laboratory Work

This research included four main laboratory stages: the first stage is concrete mixing and casting to cover the reinforcement. The second stage is model preparation, including molding, surface finishing, and finally curing. The third stage is the reinforcement-concrete bond of reference mixes of reinforcement concrete. The fourth stage is adding Olive oil mill wastewater and brine wastewater in different proportions to the optimal proportions to replace some of the regular water. All the tests were conducted at the construction laboratory of Ajloun National University. Figures 5 to 7 depict laboratory work procedures.

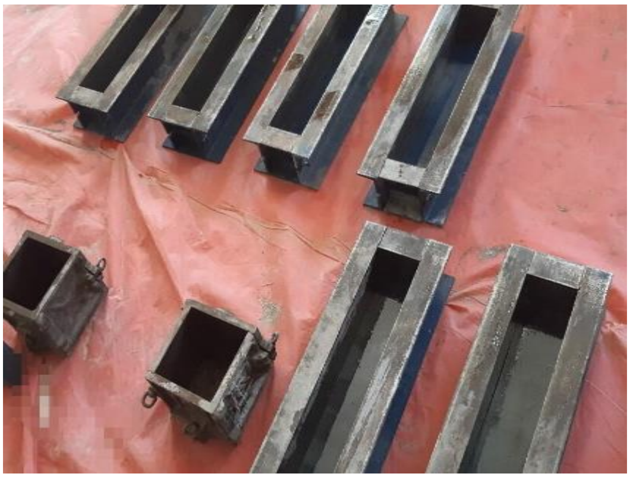


Figure 5. Beams (100×100×500 mm) and Cubes (150×150×150 mm) Specimens

Figure 6. The Samples Were Covered with Nylon

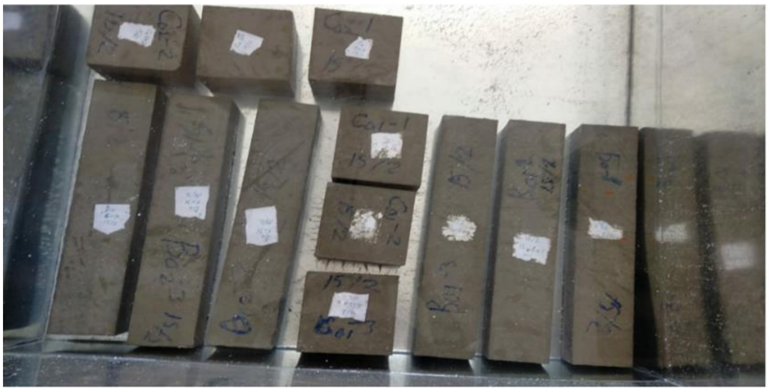


Figure 7. Torsional Beams in the Curing Stage

3.1. Concrete and Reinforcement Concrete Production

3.1.1. Cube Manufacturing

The concrete production was prepared according to the ACI testing material code for concrete. The mix of concrete is shown below:

1. 1:1.5:3 (or M 15) - (1- Cement, 1.5 – Fine Aggregate, 3- Coarse Aggregate)
2. 1:2:4 (or M 20) - (1- Cement, 2 – Fine Aggregate, 4- Coarse Aggregate)
3. 1:2:3 (or M 25) - (1- Cement, 2 – Fine Aggregate, 3- Coarse Aggregate)

Three cubes were prepared for every mix, cast, and cured for 28 days without any admixture. It has been found that the best mix ratio is 1:2:3.6 with a W/C ratio of 0.5. The compressive strength f_c' of concrete was 29.3 MPa at 28 days of curing. The mix slump test shows a 52 mm consolidation (without olive oil mill or brine wastewaters). While the compressive strength of olive oil mill wastewater was 38.69 MPa at 7.5% and 35.48 MPa for brine wastewater at 10%, the mix slump test was 97 mm and 160 mm for the olive oil mill and brine wastewater, respectively.

3.1.2. Vibrator

The vibrating table is used for model stacking.

3.1.3. Raw Materials Used

Aggregates, Cement, Water, Brine, and Olive Oil Mill Wastewater all according to Alzgool et al. [3].

3.1.4. Steel Reinforcement

The process of reinforcement of the samples (Figure 3).

3.1.5. Mixing Ratios

Table 1 shows the details of the mixing ratios used, noting that in the mixtures, part of the regular water has been replaced by a percentage of (2.5, 5.0, 7.5, 10.0, 15.0) with Olive oil mill wastewater and brine wastewater. We did not increase the percentages by more than 15% because, in previous research, the best ratios of concrete with olive oil mill wastewater were 7.5% and brine wastewater at 10%. These ratios were tested and determined for compressive and torsional strength, and it was found that an increase in these percentages leads to reduced compressive and bending strength [1-3].

Table 1. Brine Wastewaters (BW) and Olive Oil Mill (OOW) Mixes (Cubes and Beams)

Trial #	Mixture	W/C	S/C	CA/C	% of OOW, BW
0	Only concrete	0.5	1.7	3	0
1	OOW, BW	0.5	1.7	3	2.5
2	OOW, BW	0.5	1.7	3	5.0
3	OOW, BW	0.5	1.7	3	7.5
4	OOW, BW	0.5	1.7	3	10.0
5	OOW, BW	0.5	1.7	3	15.0

3.1.6. Preparing the Forms

In preparing forms for this research, US specifications (ASTM- C-192-1980) were used.

3.1.7 Molding, Surface Finishing, Removal from the Mold, Curing, and Specimen Testing

They were worked out according to Alzgool et al. [3].

3.1.8. Torsional Strength Test

At Ajloun National University, beams with dimensions of 100×100×500 mm and a hand-designed device that simulates the torsion process were used to check torsional strength according to British Specifications BS.1981.Part (118): 1983. All results are shown in Tables 2 and 3.

Table 2. Torsional Strength of Reinforced Concrete with Brine Wastewater

Number of series and percentage %	Number of samples	Measurements Beams (mm)	Average load W (kN)	Average moment (kN.m), according to Equation 3*	Average torsional moment (T) (kN.m), according to Equation 1*	Average stress (σ) (MPa), according to Equation 2	Percentage (%) stress increase
I 0.00% Control samples	1	100×100×500	1.47	0.73	0.73	4.38	-
	2						
	3						
II 2.5	1	100×100×500	1.59	0.79	0.79	4.77	9
	2						
	3						
III 5.0	1	100×100×500	1.66	0.83	0.83	4.98	14
	2						
	3						
IV 7.5	1	100×100×500	1.71	0.85	0.85	5.13	17
	2						
	3						
V 10.0	1	100×100×500	1.83	0.91	0.91	5.46	25
	2						
	3						
VI1 5.0	1	100×100×500	1.72	0.86	0.86	5.16	10.8
	2						
	3						

* As a result of equal length d = AB of both moment and the torsional moment the result will be the same.

Table 3. Torsional Strength of Reinforced Concrete with Olive Oil Mill Wastewater

Number of series and percentage %	Number of samples	Measurements Beams (mm)	Average load W (kN)	Average moment (kN.m), according to Equation 3	Average torsional moment (T) (kN.m), according to Equation 1*	Average stress (σ) (MPa), according to Equation 2	Percentage (%) stress increase
I 0.00% Control samples	1	100×100×500	1.47	0.73	0.73	4.38	-
	2						
	3						
II 2.5	1	100×100×500	1.55	0.77	0.77	4.65	6.0
	2						
	3						
III 5.0	1	100×100×500	1.58	0.79	0.79	4.74	8.2
	2						
	3						
IV 7.5	1	100×100×500	1.73	0.86	0.86	5.16	17.0
	2						
	3						
V 10.0	1	100×100×500	1.70	0.85	0.85	5.10	16.4
	2						
	3						
VI 15.0	1	100×100×500	1.38	0.69	0.69	4.14	- 5.48
	2						
	3						

* As a result of equal length d = AB of both moments, and the torsional moment, the result will be the same.

3.2. Discussion of Results

After completing the laboratory study and obtaining the results of the tests shown in Tables 2 and 3, the following analysis and discussion of the results have been concluded.

There are several factors affecting the torsion of reinforced concrete elements, including age, type of reinforcement, cement content, curing, water-to-cement ratio, brine wastewater-to-cement ratio, olive oil mill wastewater-to-cement ratio, additives, and other factors. All samples are tested after 28 days.

3.2.1. Torsional Strength of Reinforced Concrete Beams with Brine Wastewaters

Cracks began to appear in the sample at a distance of 0–10 cm from the fixed-point B on the wall (Figure 1), including in the reference samples, where they began gradually widening until the final failure occurred near the fixed-point B. But the width of the cracks in the reference samples is greater than that in the samples containing brine wastewater, where the failure occurred suddenly, and this is due to the crystallization process that occurs in the concrete resulting from the salt substance**.** In general, the failure modes of the beams with brine wastewater were similar to the failure modes of regular concrete (Figures 8 and 9).

Figure 8. Failure Modes of the Beams with Regular Water

Figure 9. Failure Modes of the Beams with Brine Wastewater

When brine wastewater is added in proportions of 2.5–10%, the torsion strength of reinforced concrete gradually increases with the ratios and is higher than that of regular reinforced concrete, where the highest was recorded at 10%. When the torsion strength equals 5.46 MPa, which is 24.66% greater than the regular samples, the torsional strength begins to decrease to 5.16 MPa. As shown in Table 2 and Figure 10, adding brine wastewater in any proportion up to 15% to reinforced concrete increases the strength of torsion significantly.

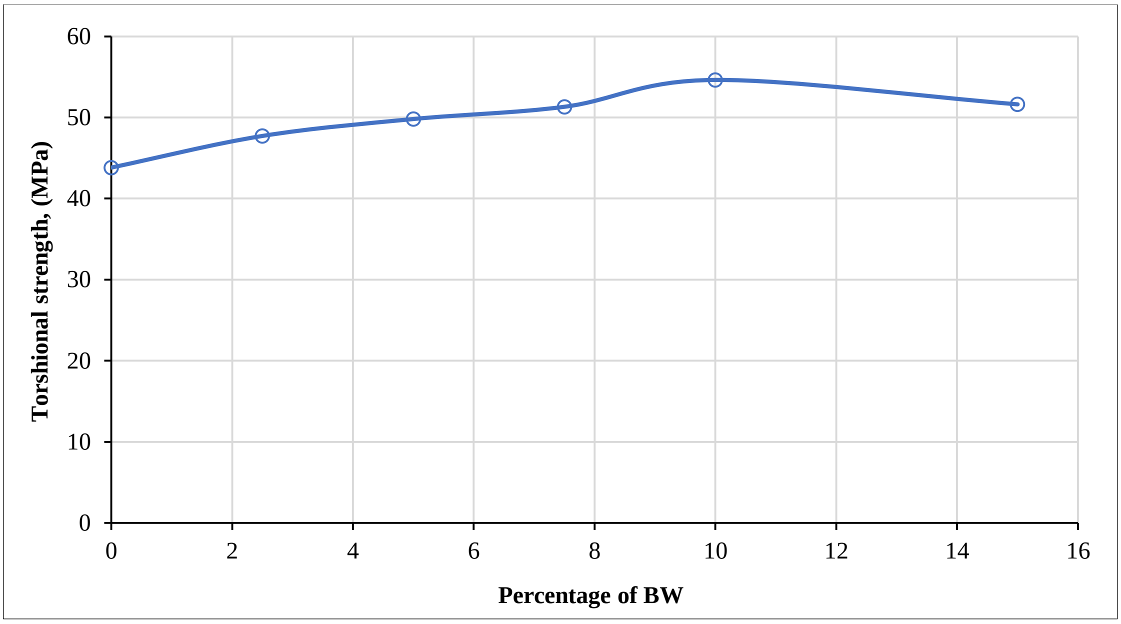


Figure 10. Torsional Strength (MPa) of Reinforced Concrete Versus Different Percentages of Brine Wastewater (BW) at 28 Curing Days

3.2.2. Torsional Strength of Reinforced Concrete Beams with Olive Oil Mill Wastewaters

Cracks began to appear in the sample at a distance of (0-10) cm from the fixed end to the wall (point B in Figure 1), including the reference samples, where they began gradually widening until the final failure occurred near the fixed point B. The process of widening cracks in samples added to olive oil mill wastewater is similar to references, in many samples to which olive oil mill wastewater was added, small cracks with an inclination angle of approximately 45^0 appeared in the area where the load was placed (point A, Figure 1). In general, the failure modes of the beams with olive oil mill wastewater are similar to the failure modes of regular concrete (Figures 8 and 11).

Figure 11. Failure Modes of the Beams with Olive Oil Mill Wastewater

Adding olive oil mill wastewater to reinforced concrete in the range of 2.5–10.0 percent increases the torsional strength. When adding 7.5%, the strength of torsion increases by approximately 8%, but then it begins to decrease and becomes 4.14 MPa when adding 15%, which is 2% less than the strength of the reference samples (Table 3 and Figure 12).

The results of the research shown in Tables 2 and 3 show different percentages of brine and olive oil mill wastewater. All results were greater than the reference samples, and it was also noticed that the torsional strength for all percentages of brine wastewater was greater than the olive oil mill wastewater. However, at 7.5 percent, both the brine and the olive oil mill torsional strengths were the same; after that, the stress in the olive oil mill wastewater decreased but remained higher than the control sample; at 15%, the stress in the olive oil mill wastewater decreased by 5.5% compared to the control mix, while the brine stress increased with the percentage increase. It reaches its maximum stress at 10% brine, with a 24.7% increase over the controlling mix. Both olive oil mills and brine wastewaters achieve the same stress at 7.5% (Figure 13 and Table 4). This is the optimum ratio for both brine and olive oil mill wastewater.

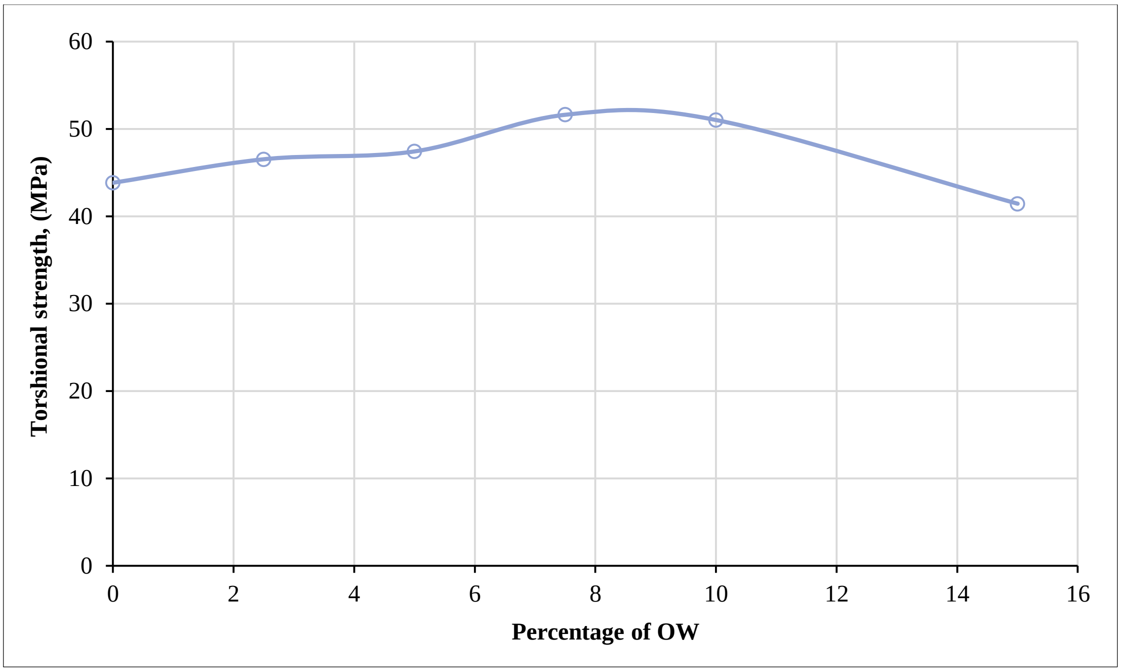


Figure 12. Torsional Strength of Reinforced Concrete Versus Different Percentages of Olive Oil Mill Wastewater (OW) for 28 Curing Days

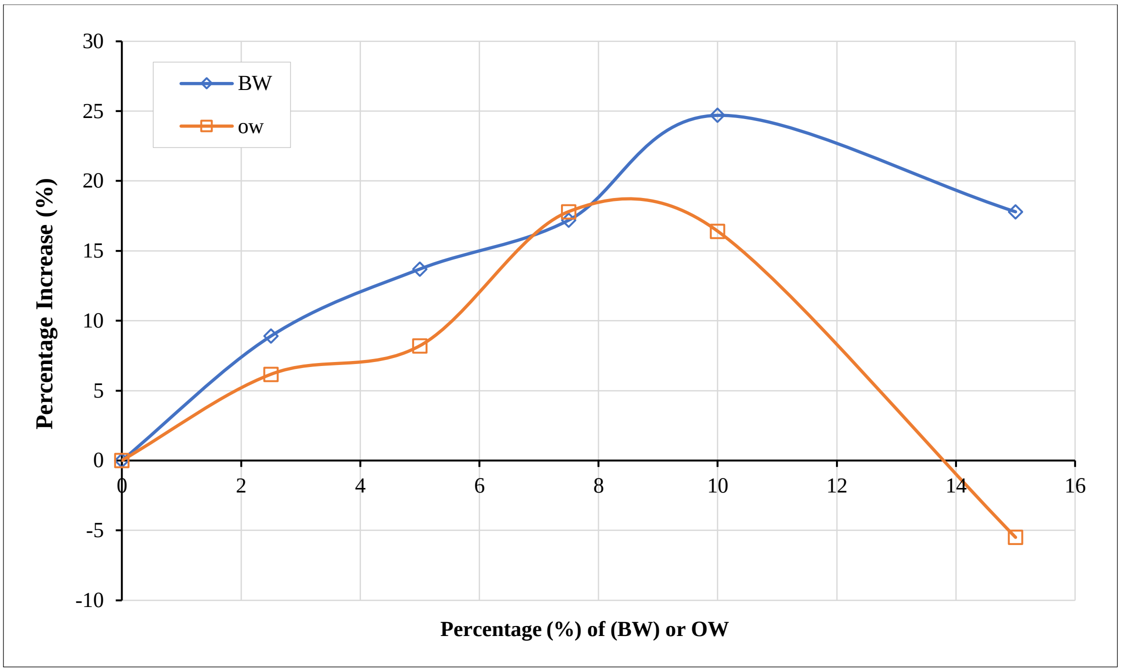


Figure 13. Percentage Increase of Stress Versus Percentage of BW and OW

Table 4. Percentage Stress Increase with an Olive Oil Mill and Brine Wastewater

No.	Percentage of BW or OW	Stress (MPa) in reference samples	Stress (MPa) in samples with olive oil mill wastewater	Stress (MPa) in samples with brine wastewater	Percentage Increase in samples with olive oil mill wastewater	Percentage Increase in samples with brine wastewater
1	0	4.38	-	-	-	-
2	2.5		4.65	4.77	6.16	8.90
3	5		4.74	4.98	8.20	13.70
4	7.5		5.1 6	5.13	17.80	17.20
5	10		5.10	5.46	16.40	24.70
6	15		4.14	5.16	- 5.50	17.8

4. Conclusion

Depending on the results and analysis of the laboratory tests, which included the production of concrete and reinforcement concrete containing the addition of brine and olive oil mill wastewaters, studying some of its properties, and comparing with the results of reference mixtures, the following can be concluded: A new concrete mix was produced by adding different percentages of brine and olive oil mill wastewater. The optimum percentages of brine and olive oil mill wastewater were 10% and 7.5%, respectively. This percentage increases the properties of the new mix significantly, according to this research, and the previous studies also confirmed this result. It was concluded that the torsional strength was a result of the addition of brine and olive oil mill wastewater by 24% and 17%, respectively. In this comprehensive research, the authors achieved two goals: saving fresh water and reducing environmental impacts. For a better understanding of the effect of adding brine and olive oil mill wastewater on the components of reinforced concrete, we recommend studying samples of reinforced concrete at ages 7, 14, 21, 90, 180, and 360 days.

5. Declarations

5.1. Author Contributions

Conceptualization, H.A.; methodology, H.A.; formal analysis, H.A.A.; investigation, H.A.A.; writing—original draft preparation, H.A.; writing—review and editing, H.A. and H.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 in the article.

5.3. Funding and Acknowledgements

The authors express their appreciation to the laboratory staff of structural engineering at Ajloun National University. The funding for this research was provided by the Scientific Research Support Funded by Ajloun National University and the Arab College University of Technology.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Alzgool, H. A., Alfraihat, A. S., & Alzghool, H. (2022). Reinforced-concrete Bond with Brine and Olive Oil Mill Wastewater. Civil Engineering Journal (Iran), 8(2), 319–333. doi:10.28991/CEJ-2022-08-02-010.

[2] Alshboul, Z. A., Alzgool, H. A., & Alzghool, H. (2022). Sustainable Use of Brine Water in Concrete Cement Mixes Alter Compression-Bending Strengths. International Review of Civil Engineering, 13(1), 67–73. doi:10.15866/irece.v13i1.20568.

[3] Alzgool, H. A. (2020). Strength characteristics of concrete with brine and olive oil mill wastewaters. International Journal of Engineering Research and Technology, 13(10), 2831–2838. doi:10.37624/IJERT/13.10.2020.2831-2838.

[4] Aras, U., Kalaycıoğlu, H., Yel, H., & Kuştaş, S. (2022). Utilization of olive mill solid waste in the manufacturing of cement-bonded particleboard. Journal of Building Engineering, 49, 104055. doi:10.1016/j.jobe.2022.104055.

[5] Kashyap, J., Willis, C. R., Griffith, M. C., Ingham, J. M., & Masia, M. J. (2012). Debonding resistance of FRP-to-clay brick masonry joints. Engineering Structures, 41, 186–198. doi:10.1016/j.engstruct.2012.03.032.

[6] Mahdi, F., Abbas, H., & Khan, A. A. (2010). Strength characteristics of polymer mortar and concrete using different compositions of resins derived from post-consumer PET bottles. Construction and Building Materials, 24(1), 25–36. doi:10.1016/j.conbuildmat.2009.08.006.

[7] Siddique, R., Khatib, J., & Kaur, I. (2008). Use of recycled plastic in concrete: A review. Waste Management, 28(10), 1835–1852. doi:10.1016/j.wasman.2007.09.011.

[8] Mostofinejad, D., & Mohammadi Anaei, M. (2012). Effect of confining of boundary elements of slender RC shear wall by FRP composites and stirrups. Engineering Structures, 41, 1–13. doi:10.1016/j.engstruct.2012.03.019.

[9] Yao, C., & Nakashima, M. (2012). Application of headed studs in steel fiber reinforced cementitious composite slab of steel beam-column connection. Earthquake Engineering and Engineering Vibration, 11(1), 11–21. doi:10.1007/s11803-012-0094-4.

[10] Ju, H., & Serik, A. (2023). Torsional Strength of Recycled Coarse Aggregate Reinforced Concrete Beams. CivilEng, 4(1), 55–64. doi:10.3390/civileng4010004.

[11] El-Mandouh, M. A., Hu, J. W., Shim, W. S., Abdelazeem, F., & ELsamak, G. (2022). Torsional Improvement of RC Beams Using Various Strengthening Systems. Buildings, 12(11). doi:10.3390/buildings12111776.

[12] Tais, A. S., & Abdulrahman, M. B. (2023). Improving the Torsional Strength of Reinforced Concrete Hollow Beams Strengthened with Externally Bonded Reinforcement CFRP Stripe Subjected to Monotonic and Repeated Loads. Information Sciences Letters, 12(1), 427–441. doi:10.18576/isl/120136.

[13] Nobuaki Otsuki, Tsuyoshi Saito, & Yutaka Tadokoro. (2012). Possibility of Sea Water as Mixing Water in Concrete. Journal of Civil Engineering and Architecture, 6(11). doi:10.17265/1934-7359/2012.10.002.

[14] Miller, S. A., Horvath, A., & Monteiro, P. J. M. (2018). Impacts of booming concrete production on water resources worldwide. Nature Sustainability, 1(1), 69–76. doi:10.1038/s41893-017-0009-5.

[15] Wegian, F. M. (2010). Effect of seawater for mixing and curing on structural concrete. IES Journal Part A: Civil & Structural Engineering, 3(4), 235–243. doi:10.1080/19373260.2010.521048.

[16] Tsagaraki, E., Lazarides, H. N., & Petrotos, K. B. (2007). Olive mill wastewater treatment. In Utilization of By-Products and Treatment of Waste in the Food Industry (pp. 133–157). doi:10.1007/978-0-387-35766-9_8.

[17] Kalkan, I., & Kartal, S. (2017). Torsional rigidities of reinforced concrete beams subjected to elastic lateral torsional buckling. International Journal of Civil and Environmental Engineering, 11(7), 969-972.

[18] Anik, M. F. R., Shihan, M. R., Brinta, F. L., & Chowdhury, S. R. (2020). A Review Paper on Increasing Torsional Strength of RC Beam using Steel Fiber Reinforced Concrete. Journal of Structural Engineering, its Applications and Analysis, 3(1), 1-10. doi:10.5281/zenodo.3895671.

[19] Zheng, Y., Zhuo, J., Zhang, P., & Ma, M. (2022). Mechanical properties and meso-microscopic mechanism of basalt fiber-reinforced recycled aggregate concrete. Journal of Cleaner Production, 370, 133555. doi:10.1016/j.jclepro.2022.133555.

[20] Rashidi, M., & Takhtfiroozeh, H. (2016). The Evaluation of Torsional Strength in Reinforced Concrete Beam. Mechanics, Materials Science & Engineering, 7, 1-11.

[21] Joh, C., Kwahk, I., Lee, J., Yang, I. H., & Kim, B. S. (2019). Torsional behavior of high-strength concrete beams with minimum reinforcement ratio. Advances in Civil Engineering, 2019, 1–11. doi:10.1155/2019/1432697.

[22] FR, K., & BH, A. B. (2016). Improvement of Torsional Resistance in Ultra-High Performance Fibre Reinforced Concrete Beams. Journal of Steel Structures & Construction, 2(1). doi:10.4172/2472-0437.1000112.

[23] Bernardo, L. F. A., Teixeira, M. M., De Domenico, D., & Gama, J. M. R. (2022). Improved Equations for the Torsional Strength of Reinforced Concrete Beams for Codes of Practice Based on the Space Truss Analogy. Materials, 15(11), 3827. doi:10.3390/ma15113827.

[24] Prakash, M., Satyanarayanan, K. S., Parthasarathi, N., Senthil, S. S., Vishal, M., & Deepakraj, V. (2022). An experimental study on reinforced concrete beam with continuous spiral stirrups under pure torsion. European Journal of Environmental and Civil Engineering, 1–13. doi:10.1080/19648189.2022.2064339.

[25] Mures, J. K., Chkheiwer, A. H., & Ahmed, M. A. (2021). Experimental Study on Torsional Behavior of steel Fiber Reinforced Concrete Members under Pure Torsion. IOP Conference Series: Materials Science and Engineering, 1090(1), 012065. doi:10.1088/1757-899x/1090/1/012065.

[26] Askandar, N. H., & Mahmood, A. D. (2020). Torsional Strengthening of RC Beams with Continuous Spiral Near-Surface Mounted Steel Wire Rope. International Journal of Concrete Structures and Materials, 14(1). doi:10.1186/s40069-019-0386-4.

[27] Yu, Z., & Shan, D. (2021). Experimental and numerical studies of T-shaped reinforced concrete members subjected to combined compression-bending-shear-torsion. Advances in Structural Engineering, 24(12), 2809–2825. doi:10.1177/13694332211012577.