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Reinforced-concrete Bond with Brine and Olive Oil Mill Wastewater

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Abstract

Since the interaction between the steel reinforcement and concrete directly controls the bond strength between them, poor bond performance results in a direct negative effect on the existing state of reinforced concrete structures. This bond is one of the most important factors affecting the strength of reinforced concrete. The bond strength is measured using the pull-out test. The present paper discusses the effect of the addition of brine and olive oil mill wastewaters to the reinforced concrete mixes. The main objective of this study is to determine the effect of brine wastewaters and olive oil mill wastewaters on the bond strength between steel and concrete when adding each of the admixtures to the concrete components. Pull-out tests were conducted on concrete mixes with additive contents of 2.5, 5, 7.5, 10, and 15 % by weight of water for each. It was found that the bonding strength of reinforced concrete specimens with an olive oil mill and brine wastewater improved and decreased by approximately 6–10% and 2–5%, respectively, if compared to the reference samples. These values were observed for mixes with additive contents of 7.5% for olive oil mill wastewaters and 10% for brine wastewaters.

Keywords: Olive Oil Mill Wastewater; Brine Wastewater; Reinforcement-Concrete Bond; Bond Strength.

1. Introduction

One of the main tasks of the national economies around the world is the improvement of construction material quality, the reduction of metals in building structures, and the efficiency of capital investments. The durability and effectiveness of structural elements when using new materials remain a major concern, including the challenge of bonding between steel reinforcement and concrete [1, 2]. The choice of new materials with low cost, durability, and environmental friendliness is a continuous challenge, especially in water-poor countries. To reduce environmental pollution, it is critical to select waste materials such as brine wastewaters and olive oil mill wastewaters [3], both of which are abundant in Jordan.

Due to climate change, pollution, industries, and the rapid increase in the population, freshwater resources are affected around the world [4-6]. More than half of the world's population will suffer from water shortages for at least one month each year by 2050. The stress on water resources is due to the rapid increase in water demand influencing the water cycle, and this shows the importance of assessing human consumption and determining the impacts on water resources.

Every year, the concrete industry consumes billions tons of freshwater for mixing and curing purposes [7]. Recent estimates have shown that concrete production has been a substantial consumer of global industrial water withdrawals.

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In poor regions, 75% of the water demand for concrete production is expected in 2050 [8]. This high rate of water needed for concrete production leads to finding sustainable alternatives such as seawater [9], brine water [12] and water discharged from wastewater treatment plants [11, 12]. Meanwhile, concrete is a major construction material, and in the past 50 years, the production rate has exceeded other building materials to the point where per capita concrete consumption exceeds the population growth rate [10]. Therefore, sustainable use of alternative water resources (e.g., brine and olive oil mill wastewaters) in concrete production will lower demand pressure on freshwater resources and reduce its environmental impact during treatment. The use of saline water in concrete mixes may change the strength and the setting time in comparison with concrete mixed with fresh water at 15 ºC. It is recommended to avoid using saltwater in reinforced concrete to prevent the corrosion of steel reinforcement [11]. However, many studies show that the negative effect of chloride ions from seawater is very small and can be neglected [7, 12, 13]. The negative environmental impact of discharged brine on the surrounding environment has encouraged researchers to explore sustainable and affordable management techniques [10, 14-16]. In this work, the possibility of using a hypersaline by-product of brine water that is discharged from Jordan's inland reverse osmosis desalination plant (Jerash Desalination Plant) and olive oil mill wastewaters has been tested, which is taken from the olive oil local pressing factory.

The use of Portland cement in concrete mixes has several environmental impacts, such as high energy consumption and greenhouse gas emissions [17, 18]. To reduce the negative impact of concrete and cement, many researchers have started to investigate the ability to use other sustainable materials [19-22]. To produce durable structural elements with a longer service life, all the effects of the addition of new materials to reinforced concrete need to be studied. It is known to us that the bonding strength between the steel and concrete is an important factor in maintaining its resistance strength and prolonging its service life in the sense that there are many tests by which we can determine the maximum bonding stress. Among the most important, simplest, and most common of these experiments is the pull-out test. Through this test, we can determine the maximum value of bonding stress between the concrete and the reinforcing bars. In addition, it gives us a direct relationship between the applied drag force and the slip that accompanies it [23, 24]. The pull-out test is based on the principle of applying a pulling force to a rebar immersed in a concrete sample of a definite length in a concrete sample of definite dimensions so that during the experiment, the applied force is recorded and the transitions of the two ends of the reinforcing bat are measured, and through these readings, a transmission load-slip curve is obtained [25, 26]. As the sample being tested collapses based on three patterns, which are: 1- Pulling the bars out of the concrete; 2- Splitting the sample; and 3- Steel bar annealing. Besides, the tension force between concrete and steel reinforcement is obtained through three main things, which are: 1- Chemical adhesion between iron and concrete, 2- Mechanical interference between rebar and concrete cores – interlocking, and 3- The frictional force that results from surface roughness and relative slip between the reinforcing bar and the surrounding concrete.

Bonding stress in reinforced concrete is useful in determining anchorage lengths. If this length is secured, the necessary resistance against sliding and dropping off the bars is secured with all bonding requirements. In the European Code EC2-2004, anchorage lengths can be found according to Equation 1:

$$L_{p,req} = \frac{\emptyset}{4} \times \frac{\sigma_{sd}}{F_{bd}} \tag{1}$$

where; $L_{p,req}$ - Anchorage length, Φ - is the bars diameter, F_{bd} – Design bond stress, σ_{sd} - Rebar stress.

The bond–stress (τ) continues the slip, many researchers have defined the relationship between bonding stress and slip-by equation that show us the bond-slip. This relationship is the CEB-FIP code, where this code, where this code presents (Figure 1) as a model Bond – Slip of a relationship [27, 28].

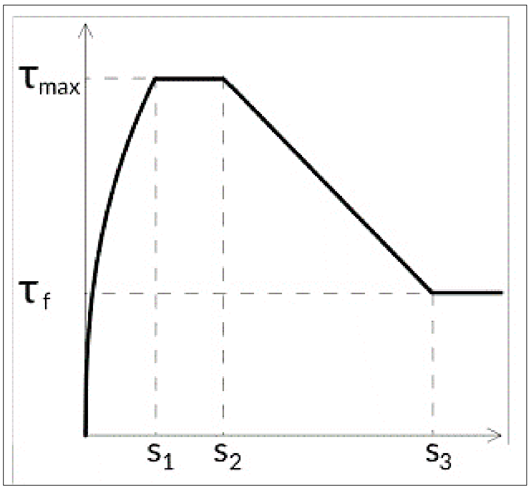


Figure 1. Analytical bond stress–slip relationship (CEB-FIP Model Code 2010)

One of the most popular standard samples for pull-out testing is RILEM – CEB RC6 recommendations, based on which we can obtain a curve (P-S), and the bond strength is obtained through Equation 2 [27, 28]:

$$\tau = \frac{P}{\pi \emptyset La} \tag{2}$$

where τ is the bond strength, P is the applied load, Φ is the bars diameter, and La is anchorage length. We have to rely on the constants of RILEM – CEB RC6 (1983), when we put forward the use of reinforced concrete to which olive oil mill and brine wastewaters are added and compare it with the EC2-2004 code.

To find the bonding strength in reinforced concrete containing brine wastewaters and Olive Oil Mill Wastewaters, samples were prepared containing 2.5, 5.0, 7.5, 10.0, and 15.0 % percent of normal water content. The specimens are cylinders measuring 150×300 cm of concrete, and a steel bar was poured into the center of the sample and tested according to the ASTM C900 -19. Samples with ratios of more than 15% were not used, and this is due to previous studies [29-32], which proved that the use of ratios greater than 15% leads to weak strength concrete on compression and bending.

2. Materials and Methods

2.1. Olive Oil Mill Wastewaters

In the previous studies [31, 32], the material from olive oil mill wastewaters was studied in detail. Table 1 shows the specifications of the olive oil mill wastewaters that were used in this research, which were taken from an olive oil mill 5 km away from the university campus. The samples were collected directly from the discharge outlet and transported in sealed, non-nonreactive containers. The olive oil mill wastewater was used within three days after collection to ensure that the properties were not changed, and the physico-chemical properties of samples were collected from the plant's laboratory.

Table 1. Characterization Olive Oil Mill Wastewaters

Property	Ph	COD (kg)	BOD (kg)	PhCn (kg)	TS (kg)	VS (kg)
Value	5.37	54.56	18.58	2.01	46.47	37.07

2.2. Brine Wastewaters

The physical and chemical specifications of the brain wastewaters used in this research are shown in Table 2. To learn more, you can review previous studies [31, 32].

Table 2. Chemical and physical properties of Braine wastewaters

Test	Unit	Sample		
		Feed Water	Brain	Final Product
HCO_3	Mg/l	229.36	543.7	145.75
Ca^{+2}	Mg/l	100.60	230.1	76.75
CO_3^-	Mg/l	0	0	0
CL^-	Mg/l	363.17	720.9	263.41
TDS	Mg/l	1167	3630	851.4
Total Hardness	Mg CaCo3/L	560	1220	395
K^+	Mg/l	4.69	9.5	3.91
Mg^{+2}	Mg/l	61.29	130.4	49.61
Na^+	Mg/l	178.48	270.5	140.76
CO_3^-	Mg/l	0	0	0
pH	Mg/l	7.56	7.4	7.07
SO_3^{-2}	Mg/l	143.4	285.2	134.4
Fe	Mg/l	<0.1	<0.1	<0.1
Residual chlorine	Mg/l	0.3	0.3	1.5
Cu^{+2}	Mg/l	<0.02	<0.02	<0.02
NH_3	Mg/l	<0.1	<0.1	<0.1
AL^{+2}	Mg/l	<0.03	<0.03	<0.03
Residual Cl	Mg/l	1.2	1.0	0
NH_3	Mg/l	<0.1	<0.1	<0.1
Cu^{+2}	Mg/l	<0.02	<0.2	0.02
F^-	Mg/l	<0.2	<0.2	0.65
Fe^{+2}	Mg/l	<0.10	<0.10	<0.10

2.3. Silica Sand

It results from sandy rocks that turn white mainly composed of medium and fine (quartz) granules with grains ranging in size between (1.0-5.0) microns and has a good spherical 4 shape. Its purity reaches more than (98%) and the chemical formula of these rocks is (SiO2) sand. Silica is widely used in silicic and ceramic industries because it prevents the occurrence of cracks since it reduces shrinkage rate and plasticity as well as helps with exit gases released into the ceramic body, the chemical composition of silicate sand in Table 3. Table 4 shows the sieve analysis. Note: this substance is available locally in large quantities in Alazraq area in Jordan.

Table 3. The chemical properties of the sand (as provided by the Royal Scientific Society in Jordan)

Component	LOI	Si	CaO	F	S	MgO	A	NO	O	Ti
Content (%)	2.84	93.71	0.23	0.10	1.57	0.06	0.95	0.07	0.32	0.15

Table 4. Sieve analysis of used silica sand

Sieve(in)	No.4	No.8	No.10	No.16	No.30	No.40	No.50	No.100	No.200
Finer percent (%)	100	99	98	97	81	65	40	5	2.9

2.4. Cement

Ordinary Portland cement, Type I (ASTM C-150) classification system, which is widely used in general, was used in this study. The cement was made mainly from calcareous materials, such as limestone/chalk, and silica and alumina found as clay or shale. Minor compounds also exist in cement such as MgO, TiO2, Mn2O3, K2O, and Na2O. The main ingredients of cement are listed in Table 5. Cement chemists use abbreviated symbols as a shortened notation which describes each oxide by one letter: (CaO = C, SiO2 = S, Al2O3 = A, and Fe2O3 = F) [33].

Table 5. Main compounds in Portland cement

Name of compound	Oxide composition	Abbreviation
Tricalcium silicate	3 CaO. Si	C_3S
Dicalcium silicate	2 CaO. Si	C_2S
Tricalcium aluminate	3 CaO. A	C_3A
Tetracalcium aluminoferrite	4 CaO. A F	C_4AF

The silicates are responsible for the strength of hydrated cement paste. The presence of C3A contributes to the early-stage strength of cement. When the sulfates attack the hardened cement, the calcium sulfoaluminate (ettringite) forms and may cause disruption. The compound C4AF contributes in a minor way to the behavior of cement; it reacts with gypsum to form calcium sulfoferrite to accelerate the hydration of silicate. Table 6 shows the approximate composition limits of Type I Portland cement [33].

Table 6. Approximate composition limits of Type I Portland cement

Compound composition	C_3S	C_2S	C_3A	C_4AF	$CaSO_4$	Free CaO	MgO	LOI
Content (%)	59	15	12	8	2.9	0.8	2.4	1.2

2.5. Steel Reinforcement

The steel reinforcement used in the research was tested and the results were recorded in Table 7. It was found that the steel reinforcement used conformed to the specifications of (Grade 60) according to the American specification.

Table 7. The results of the steel reinforcement tensile-tests used in the research

Diameter D (mm)	Samples No	Length (mm)	Tensile Force (kN)	Average tensile Force (kN)	F_y (kN)	Average F_y (kN)
14	1	493	105.10	105.40	85.84	86.58
	2	515	104.30		87.30	
	3	515	106.80		86.60	
16	1	505	109.91	109.80	85.86	87.36
	2	505	111.88		88.93	
	3	500	107.62		87.31	

3. Experimental 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 wastewaters and brine wastewaters in different proportions to the optimum proportions to replace part of the regular water.

3.1. Reinforcement Concrete Production

The raw materials used (cement, coarse and fine aggregate) were mixed in ratios listed in Table 8. In addition to Olive oil mill wastewater used in Table 1, Brine water was used in Table 2, and Steel reinforcement - Steel diameter 14 and 16 (grade 60) was used in Table 7. The mix design of all concrete mixtures is listed in Table 9.

Table 8. Raw materials mix design for one concrete cylinder

Aggregate Type	Weight (Kg)	Passing number
Cement	2.078	-
Water	1.484	-
Coarse aggregate CA	6.349	$\frac{3''}{4}$ (19 mm) $-\frac{1''}{2}$ (9.5 mm)No. 4, (4.75 mm) $-$ (30 mm)
Silica sand	3.604	2 mm $-$ 0.075 mm

Table 9. Olive Oil Mill Wastewaters (OOW) and Brine Wastewaters (BW) mixes (Cylinders)

Trial #	Mixture	W/C	S/C	CA/C	% of OOW, BW
0	Only concrete				0
1	OOW, BW				2.5
2	OOW, BW	0.7	1.7	3	5
3	OOW, BW				7.5
4	OOW, BW				10
5	OOW, BW				15

Moldings

The standards have been approved (B.S.1881.part (116):1989), and (B.S.1881.part (118):1983) [31, 32]. In preparing the models for this research, in which the molds 150×300 mm, cylinders used should be of a non-absorbable material (Figure 2). After the mixing process was completed, the concrete and reinforcement concrete were placed with the molds and was stacked using electric vibrators for a suitable time (one minute for each layer) until the concrete and reinforcement concrete inside the mold was level, with the sides of the mold being checked after each compaction.

Figure 2. Sample processing

Surface Finishing

After filling the molds, the surface of the samples was modified and flattened. Then, all the samples were covered with nylon to prevent water evaporation and to obtain a suitable surface for examination.

Removal from the mold

All forms with brine wastewaters were removed from the molds after 24 hours, and all forms with olive oil mill wastewaters were removed from the molds after 48 hours instead of 24 hours from the time of casting. The reason for the delay in dismantling the molds is the need for concrete, with added Olive oil mill wastewater for more time, to solidify.

Curing

After the samples were removed from the molds, they were flooded with water until the testing period (Figure 3).

Figure 3. Curing process

3.2. Specimens Testing

The tests were performed on reference mixtures and mixtures containing different proportions of Olive oil mill wastewaters and Brine wastewaters. All tests' durations were 35 days for all mixtures.

Pull-Out bond test

All mixtures were tested at 35 days. Cylinders with dimensions 150×300 mm were used to check force bonding according to ASTM C900-19, and by using a Universal Testing Machine, with scan capacity of 1200 kN in tension and compression; mainly tensile strength for steel bars up to 50mm diameters (Figure 4). All steel bars were installed in the center of the cylinder and inserted at a distance of two-thirds of the length of the cylinder 20 cm. The results of the tests were recorded in Tables 10 to 13.

Figure 4. Sample screening device reinforcement- concrete bond

Table 10. Cylinder characteristics and results of the pull-out bond test (ϕ 14 Grade 60) from concrete with olive oil mill wastewater

Number of series	Number of samples	Concrete of Durability (MPa)	Length of the Sample (mm)	Pull-out Force (kN)	Average Pull-out Force (kN)	Average Bounding Stress (MPa) according Eq. 2
I-2.5%	1	32.06	300	47.9	48.10	5.47
	2			48.78		
	3			47.63		
II-5%	1	33.63	300	46.92	47.08	5.35
	2			47.22		
	3			47.10		
III-7.5%	1	38.69	300	45.98	46.30	5.26
	2			46.20		
	3			46.71		
IV-10%	1	34.52	300	44.95	44.93	5.11
	2			44.73		
	3			45.12		
V-15%	1	26.37	300	38.21	37.96	4.31
	2			38.15		
	3			37.33		
VI-Control sample	1	28.94	300	49.50	49.47	5.62
	2			49.98		
	3			48.95		

Table 11. Cylinder characteristics and results of the pull-out bond test (ϕ 16 Grade 60) from concrete with olive oil mill wastewater

Number of series	Number of samples	Concrete of Durability (MPa)	Length of the Sample (mm)	Pull-out Force (kN)	Average Pull-out Force (kN)	Average Bounding Stress (MPa) according Eq. 2
I-2.5%	1	32.06	300	47.05	47.09	4.69
	2			47.91		
	3			46.31		
II-5%	1	33.63	300	45.82	45.26	4.51
	2			45.20		
	3			44.78		
III-7.5%	1	38.69	300	44.58	44.42	4.42
	2			43.90		
	3			44.80		
IV-10%	1	34.52	300	40.34	40.29	4.00
	2			39.33		
	3			41.22		
V-15%	1	26.37	300	34.83	35.69	3.56
	2			36.91		
	3			35.33		
VI-Control sample	1	28.94	300	50.43	49.29	4.91
	2			49.52		
	3			47.92		

Table 12. Cylinder characteristics and results of the pull-out bond test (ϕ 14 Grad 60) from concrete with Brine wastewaters

Number of series	Number of samples	Concrete of Durability (MPa)	Length of the Sample (mm)	Pull-out Force (kN)	Average Pull-out Force (kN)	Average Bounding Stress (MPa) According Eq. 2
I-2.5%	1	31.76	300	44.92	44.12	5.01
	2			43.33		
	3			44.12		
II-5%	1	32.23	300	45.66	45.86	5.21
	2			45.82		
	3			46.11		
III-7.5%	1	33.49	300	46.10	46.66	5.30
	2			47.01		
	3			46.87		
IV-10%	1	35.48	300	48.98	48.42	5.51
	2			47.96		
	3			48.32		
V-15%	1	27.26	300	46.90	46.83	5.32
	2			47.60		
	3			45.99		
VI-Control sample	1	29.21	300	49.50	49.47	5.62
	2			49.98		
	3			48.95		

Table 13. Cylinder characteristics and results of the pull-out bond test (ϕ 16 Grad 60) from concrete with Brine wastewaters

Number of series	Number of samples	Concrete of Durability (MPa)	Length of the Sample (mm)	Pull-out Force (kN)	Average Pull-out Force (kN)	Average Bounding Stress (MPa) According Eq. 2
I-2.5%	1	32.06	300	39.22	39.31	3.91
	2			40.15		
	3			38.55		
II-5%	1	33.63	300	40.79	40.56	4.04
	2			39.80		
	3			41.11		
III-7.5%	1	38.69	300	44.73	44.53	4.43
	2			43.85		
	3			45.02		
IV-10%	1	34.52	300	46.73	46.88	4.66
	2			47.05		
	3			46.87		
V-15%	1	26.37	300	45.98	45.44	4.52
	2			45.43		
	3			44.93		
VI-Control-sample	1	28.94	300	50.43	49.29	4.91
	2			49.52		
	3			47.92		

3.3. Results and Discussion

In reinforced concrete, the factor of bonding reinforced steel with concrete is one of the most important factors that make the two materials work as one material characterized by its high strength of compression, bending, tensile, torsion, and other properties [1, 2]. When a new material is added to the components of reinforced concrete, this factor acquires a special character due to its importance. In this research, cheap and environmentally important materials were used, especially for the countries of the Mediterranean basin, including Jordan. These materials were olive oil mill Wastewaters and brine Wastewaters.

3.3.1. Reinforced-Concrete Bond with olive oil mill Wastewater

The bonding factor was carefully studied as different diameters of reinforcement steel were used (Grade 60, diameters 14, and 16). Concrete was also used with different proportions of olive oil mill wastewater and compared with reference samples. For each steel diameter, 18 samples were used—three reference samples and fifteen samples in different proportions—and all the results are recorded in Tables 10 and 11. After testing all the samples, it was found that olive oil mill wastewater has a direct effect on the bonding strength between reinforcement steel and concrete. From Tables 10 and 11 and Figure 5, it is clear that the greater the percentage of olive oil mill wastewaters added, the lower the bonding stress, and this is due to the presence of the oil substance, which was originally one of the components of olive oil mill wastewaters. It is known to us that oil material reduces the force of friction, which is an important factor for the bonding strength between concrete and rebar. The higher the percentage of olive oil mill wastewater, the lower the bonding strength between steel reinforcement and concrete. This was observed for all diameters of steel that were used, regardless of the tensile strength of steel (Tables 10 and 11, and Figure 5). The strength of concrete resistance in all ratios is up to 10%, which is greater than the reference samples, after which the resistance begins to gradually decrease. Although the strength of concrete in samples to which olive oil mill wastewaters are added for all ratios is higher than that of the reference samples, the bonding strength for all ratios is lower, as was explained above.

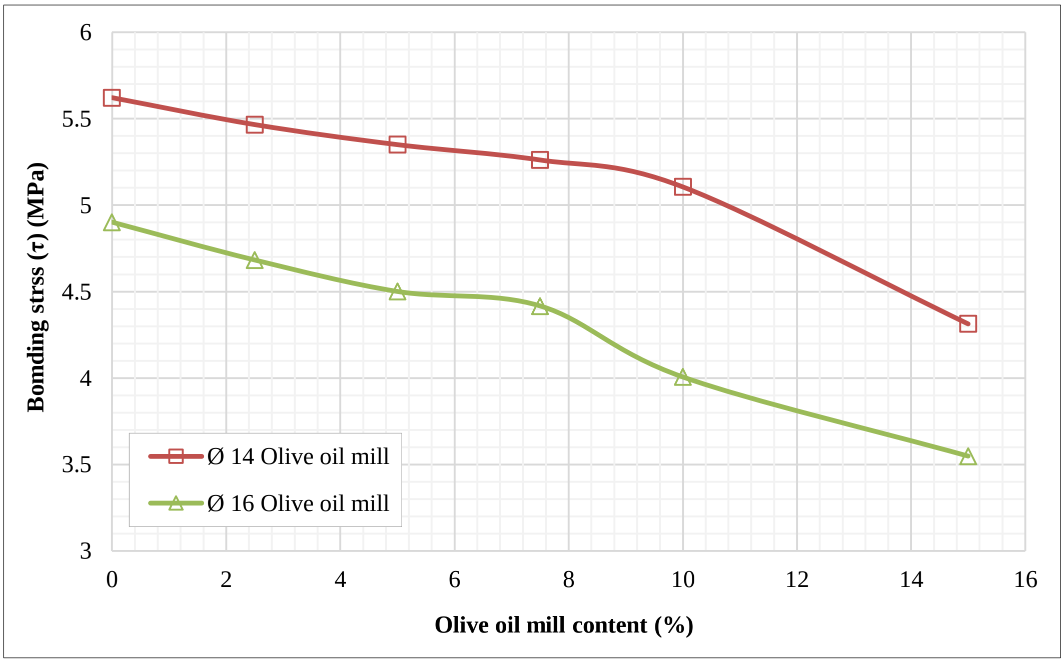
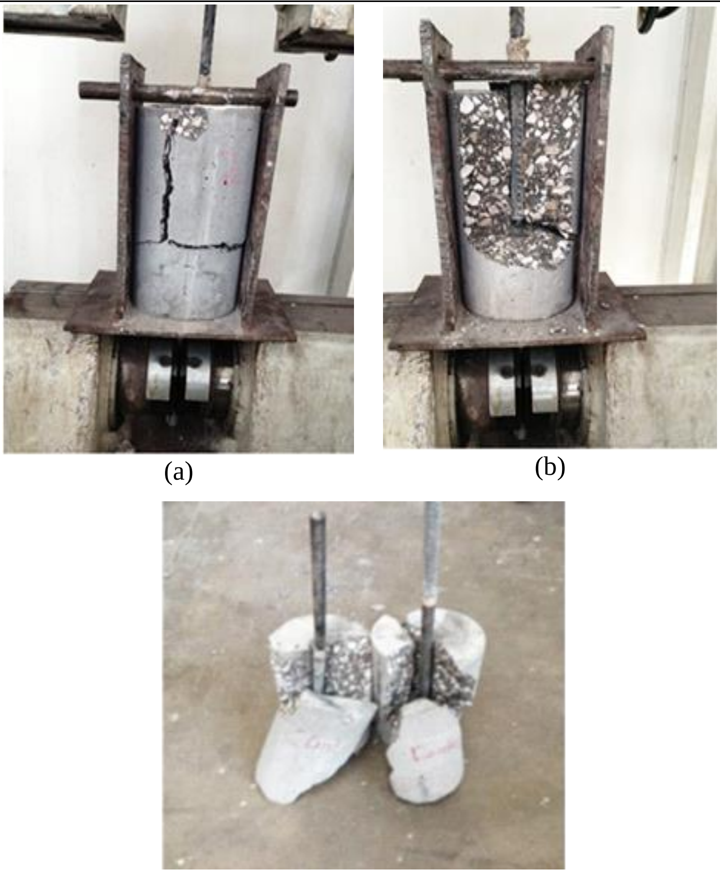


Figure 5. Reinforcement-Concrete Bond Mixes of Different Olive Oil Mill Wastewaters at 35 Days of Curing

As previously mentioned, the best percentage of olive oil mill wastewaters, which gives us the best strength, is 7.5%. However, the bonding strength of this percentage is less than that of ordinary concrete, ranging from 6% to 10%, according to the diameter of the reinforcement steel that was used. Based on the aforementioned information, on the basis of this, we advise not to use a ration higher than 7.5% when adding them to reinforced concrete, and at the same time, this percentage is sufficient to make concrete workability excellent and it does not need any additives. Based on the discussed results and analysis, and given that the compression and bending strength of concrete are higher than usual, we suggest designing the introduction of a safety factor called the bonding factor, and we will symbolize it as (η) to compensate for this decrease. The failure modes of all cylinders except for the reference or with olive oil mill wastewaters and for different diameters of reinforcement steel were similar (Figures 6 and 7). The cracks were gradually observed and widened along with the distance of the steel rod inside the sample, which was 20 cm, until the sample failed or collapsed permanently, which is in line with such testing, clarification of the EC2-2004, RILEM–CEB RC6 (1983), and many researchers [26-30].



(a) (b)

(c)

Figure 6. Failure modes of the cylinders: a and b- General failure form of the testing samples, c. Failure modes of the control samples

Figure 7. Failure modes in different cylinders with Olive oil mill wastewaters

3.3.2. Reinforcement-Concrete Bond with Brine Wastewaters

As we mentioned above, when adding any new material to the components of reinforced concrete, it must be carefully considered, especially the strength of the bonding between steel and concrete. Accordingly, when adding brine wastewaters, it was studied in the same way as indicated in section (3.3.1) related to olive oil mill wastewaters, where the same bares and the same proportions were used and the same number of samples. All the results were recorded in Tables 12 to 15.

After testing all the samples, it was found that brine wastewater has a direct effect on the bonding strength between reinforcement steel and concrete. This is due to the presence of the salt substance, which was originally one of the components of brine wastewater. Increasing the brine wastewater leads to a decrease in the bonding strength between steel reinforcement and concrete. This was observed for all diameters of steel that were used, regardless of the tensile strength of steel. However, the decrease in the bonding strength here is greater than the small percentage, i.e., 2.5%, where the value was 10–20% depending on the diameter of the steel used. After that, the decrease in the bonding strength began to decrease as we increased the percentage of brine wastewaters until the value reached 2–5% at a percentage of 10% for brine wastewaters, and then it began to gradually rise again (Tables 12 and 13, and Figure 8).

Table 14. The value of the Coefficient "η" in the Equation 3, when adding olive oil mill wastewaters

NO.	Type and beam Characteristics	Diameter Of reinforced Steel (D, mm)	Recommended Coefficient "η"
1	Without olive oil mill wastewaters	14	1
	0.00% (Control)	16	1
2	With olive oil	14	0.970
	mill wastewater 2.5%	16	0.955
3	With olive oil	14	0.955
	mill wastewater 5.00%	16	0.920
4	With olive oil	14	0.930
	mill wastewater 7.5%	16	0.900
5	With olive oil	14	0.910
	mill wastewater 10%	16	0.82
6	With olive oil	14	0.770
	mill wastewater 15%	16	0.73

Table 15. The value of the Coefficient "η" in the Equation 3, when adding brine wastewaters

NO.	Type and Beam Characteristics	Diameter Of reinforced Steel (D, mm)	Recommended Coefficient "η"
1	Without olive oil mill wastewaters	14	1
	0.00% (Control)	16	1
2	With olive oil	14	0.9
	mill wastewater 2.5%	16	0.80
3	With olive oil	14	0.93
	mill wastewater 5.00%	16	0.83
4	With olive oil	14	0.95
	mill wastewater 7.5%	16	0.90
5	With olive oil	14	0.98
	mill wastewater 10%	16	0.95
6	With olive oil	14	0.95
	mill wastewater 15%	16	0.92

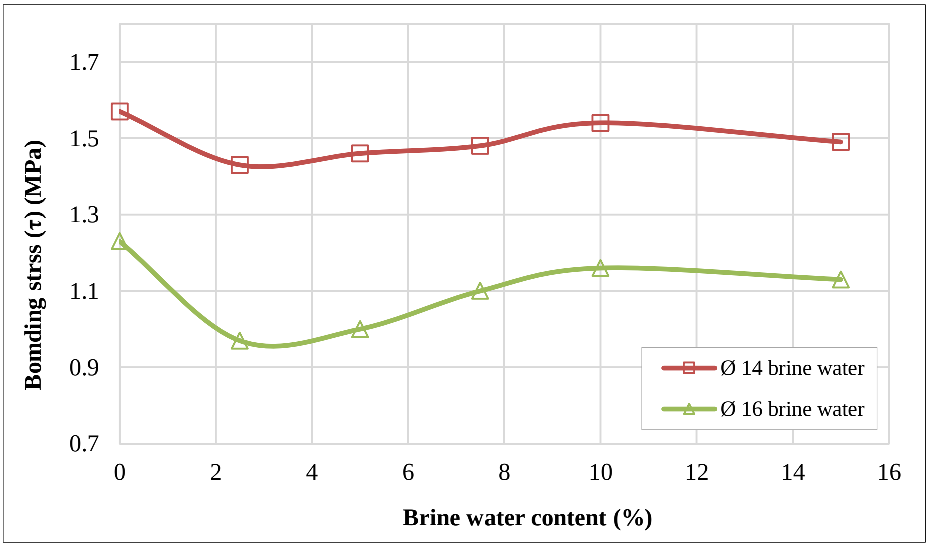


Figure 8. Reinforcement-Concrete Bond Mixes of Different brine Wastewaters at 35 Days of Curing

As previously mentioned, the best percentage of brine wastewaters, which gives us the best strength, is 10%, If we look at Tables 12, 13, and Figure 8, we find that the bonding strength in the samples to which the brine wastewaters is added is close to the reference samples, and higher than the samples to which olive oil mill wastewaters has been section (3.3.1). However, the bonding strength of this percentage is less than ordinary concrete from 2 – 5% according to the diameter of the reinforcement steel that was used. It is also clear to us that the smaller the diameter of the steel, the higher the bonding strength, which applies to ordinary reinforced concrete, this has been scientifically proven and explained in the international regulations related to design. It is also clear that small percentages of up to 2.5% have a negative effect on the bonding strength, as it is not sufficient to form the crystallization process in concrete that help generate the bonding strength. Based on the results and analyses, and as was done above in section (3.3.1), we will enter the bonding coefficient to find a decrease in the ratio of the bonding strength between steel and concrete to which brine wastewaters are added, and we will symbolize it as (η).

The failure modes of all cylinders except for the reference or with brine wastewaters and for different diameters of reinforcement steel were similar (Figures 6-c and 9). The cracks were gradually observed and widened along with the distance of the steel rod inside the sample, which is (20 cm) until the sample failed or collapsed permanently, which is in line with such testing, clarification of the EC2-2004, RILEM – CEB RC6 (1983), and many researchers [26-30].

(a) (b)

Figure 9. Failure modes in different cylinders with brine wastewaters

Experiments have indicated that the durability really decreases at a lower bond. The principal factors influencing the durability are, the degree of adhesion, percentage and the kind of the reinforcement, the surface of rebar, anchored length, the kind and the class of the concrete. Taking into consideration other equal conditions it is suggested to take into accounts the influence of the bond using coefficient (η), which should be multiplied by the value of the moment of rupture for the given concrete conditions according to the code. If we take for example, reinforced concrete beam with the lower reinforced – concrete bond may be defined according to the Equation:

$$M_u = M_{umax} \times \eta \tag{3}$$

where $M_{u\,max}$ is the maximum moment of complete bond, calculated according to the code and η is the coefficient of the decrease of the beam's durability at the lower bond, its values obtained by our testes are given in Tables 14 and 15. We succeeded in getting the dependence of the moment of the deflection on the level of adhesion by the least square's method:

$$M_u = M_{umax} \times \left(\frac{\eta_n}{\eta_n + 0.34} + 0.7\right) \tag{4}$$

$$\eta_n = \frac{\tau_{m,x}}{\tau_m} \tag{5}$$

where η_n is the ratio of average values of stresses of concrete bond in the elements with lower bond and the analogous parameter of complete adhesion. Equation 4 is based on hypothetical values. To determine accurate values of η_n parameter, various experiments must be carried out on structural elements of reinforced concrete, to which olive oil mill and brine wastewaters are added, taking into account the different ratios specified in the above research. The most important objectives that were put forward in this research is to examine the extent to which to olive oil mill and brine wastewater affects the bonding strength between reinforcement steel and concrete. With reference to the results shown in sections (3.3.1) and (3.3.2), it is clear that the bonding strength is very encouraging. Accordingly, research must continue on the elements of reinforced concrete including tension, bending and torsion to reach the main goal, which is developing a proposal for instructions in order to add an olive oil mill and brine wastewater in the production of reinforced concrete, because of its environmental and economic importance and the provision of fresh water.

4. Conclusions

Based on the experimental work, results, and analysis, the following can be concluded:

- The bond strength between reinforcement steel and concrete decreases by no more than 10% when olive oil mill wastewater is added up to 7.5%.
- The bonding strength between reinforcement steel and concrete decreases by no more than 5% when brine wastewater is added by 10%, which is the best percentage that can be provided to concrete, where the best strength is obtained in bending and compression.
- Reinforced concrete can be produced by replacing part of the regular water with the proportions of brine and olive oil mill wastewater.
- Because of the encouraging results for the bonding strength between reinforcement and concrete, in addition to the excellent standing strength on compression and bending of concrete added to the olive oil mill and brine wastewater, we recommend a detailed study regarding the impact of these materials on steel reinforcement.
- It was found that olive oil mill and brine wastewater have a direct effect on the bonding strength between reinforcement steel and concrete. Therefore, we recommend carrying out an extensive study of the elements of reinforced concrete added to these materials in different proportions in compression, bending, and torsion to find the bonding factor (η_n) in Equation 4, and in order to ascertain the values of (η).

5. Declarations

5.1. Author Contributions

H.A.A.: Prepared and tested specimens, obtained results, and reviewed the manuscript. A.S.A.: Analysis of the results. H.A.: Manuscript writing. 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.

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5.4. Conflicts of Interest

The authors declare no conflict of interest

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