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Mechanical and Physical Properties of Concrete Mixed Using Dead Sea Water

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Abstract – *The rapid increase in the world's population has resulted in a shortage of water, especially in developing countries. To conserve fresh water, the utilization of seawater in the concrete industry is being considered as a viable alternative due to its abundance. Additionally, seawater is more easily accessible in coastal regions, which can promote their development. In this study, the effect of using Dead Sea Water (DSW) as a mixing water for concrete was investigated. Several concrete mixes were produced using DSW mixed with fresh water at different percentages of 0, 25%, 50%, 75%, and 100%. In addition, the cement content was also changed between 300 to 350 kg/m^3 to produce concrete of different strengths ranging from 30 to 44 MPa. Fresh and hardened properties including the slump, air content, density, and compressive and tensile strengths at different ages between 7 to 90 days were investigated. Compared to the reference mix (0% DSW), the concrete produced using DSW provided lower slump values, higher air contents of up to 20%, and lower density of up to 17%. The compressive strength and splitting tensile strength decreased by 30% to 85% and 15% to 75%, respectively, as the percentage of DSW in the mix increased from 25% to 100%. It was found that the use of DSW in concrete can severely impact its fresh and hardened properties.*

***Keywords**: Dead Sea Water, Concrete, Strength, Slump, Density, Air Content*

I. Introduction

Sea water, commonly referred to as saltwater or ocean water, is an essential component of the Earth's hydrosphere. It covers around 71% of the planet's surface and is critical to global climate, ecology, and a variety of human activities. Seawater differs from freshwater due to its high salinity, which is caused mostly by the dissolved salts and minerals it contains. Its features, composition, and distinct ecosystems make it a topic of intense scientific research as well as an important resource for a variety of marine-related sectors including pipe selection of sea water cooling system main engine 60M patrol boat using weight loss method based on predictive maintenance [1], analysis of salinity from seawater on physical and mechanical properties of laminated bamboo fiber composites with an epoxy resin matrix for ship skin materials [3], and hazard and operability (HAZOP) study at separation system in the offshore platform [2] . Because this study analyzes the influence of sea water on the characteristics of fresh and hardened concrete, special attention must be made to the concrete under consideration. Concrete is the most globally consumed material and the base of modern development. Concrete production consumes huge quantities of the available natural resources including water. Several billion tons of fresh water is consumed annually for mixing and curing of concrete, while there are several cautions against using seawater in this industry. There is a severe shortage around the world in drinking water. In a country like Jordan which is considered the second globally water-scarce country, less than one hundred cubic meters per capita per year is available from the renewable resources of water [11].

Therefore, it is necessary to investigate the mechanisms of utilizing seawater in the concrete industry and how it may impact its properties [12]-[14]. Additionally, seawater is more easily accessible in coastal regions, which can promote their development. Seawater contains about 35,000 ppm-dissolved salts, its total salinity is approximately 3.5%, of which 78% is sodium chloride [12]. The pH value of seawater varies between 7.4 and 8.4.

Corrosion of reinforcing steel occurs below a PH of 11 [15]. The Dead Sea is located in the Jordan Rift Valley on the western border of Jordan. Dead Sea salinity is amongst the extremes worldwide is about 31.5%. Dead Sea water contains about 335 mg of slats per litter and about its half is magnesium chloride followed by the chlorides of calcium and sodium [16], [17]. Concrete structures often deteriorate due to the corrosion of concrete caused by exposure to detrimental chemicals present in nature, such as those found in seawater or some ground waters sea waters. Among these chemicals, chlorides, and sulfates are considered the most aggressive and have a significant impact on the long-term durability of concrete structures.

Portlandite leaching rate is increased by dissolving chlorides in the water, leaving the concrete at a higher porosity texture, and eventually leading to a loss of the

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concrete strength and stiffness. Similarly, calcium, sodium, magnesium, and ammonium sulfates can harm concrete by causing expansion, spalling, and strength loss due to the reaction with the hydrated cement paste, with increasing hazards in that order [18]. The extent of deterioration of hardened cement paste due to exposure to detrimental chemicals primarily depends on three factors: the concentration of chemicals, duration of exposure, and concrete properties [16]. Several additives can be used to promote concrete strength and increase its deterioration resistance.

Ceramic powder concrete [19] and ground granulated blast furnace slag concrete [10] are examples of such additives that are used in order to increase the concrete compressive strength and reduce the impact of salts on concrete properties. Additionally, epoxy-coated reinforcement [8], [11] and high-quality reinforcement such as fiber-reinforced polymers [22], [23] could be used to delay steel corrosion in salty water. The effect of seawater and Dad Sea water on concrete has been extensively investigated. However, its effect is usually investigated for exposure conditions [24]-[26] and less attention is paid to its use as mixing water [27], [28]. The behavior of concrete mixed and cured with Nembe seawater was investigated [4], fly ash and Met kaolin were used to enhance concrete properties mixed and cured using sea water [5]. The effect of sea water on the time setting of concrete [6], compressive strength [7] and structural concrete [8] was studied using different curing regimes.

Also, effects of seawater, NaCl, and Na_2SO_4 solution mixing on hydration process of Cement paste were investigated [10]. In this study, a comprehensive experimental program was conducted to investigate the effect of utilizing Dead Sea water on the mechanical and physical properties of concrete. The principal goals of this experimental investigation are to thoroughly evaluate the potential effects of using Dead Sea Water (DSW) as a mixing ingredient in the production of concrete. The investigation is going to start with investigating the chemical composition of DSW to determine its potential effect on concrete qualities. It is scheduled to conduct a number of tests, including the slump test, to determine the workability of DSW-mixed concrete. The density of these concrete mixtures will be investigated to discover any differences caused using DSW. The air content of new concrete mixes will be measured in order to determine how it affects the consistency of the mixture. Furthermore, the study will investigate the compressive and tensile strengths of concrete specimens, with a primary focus on the material's structural integrity when DSW is included in the mix.

These goals attempt to give a thorough understanding of the effects of DSW on the chemical and mechanical characteristics of concrete, allowing for insights into its practical application in construction and its potential as a sustainable alternative to freshwater.

This paper is arranged in four sections, the first section presents an introduction providing a background and the latest research regarding the paper topics, the second section presents the properties of the used materials and the details of the followed methodology, the results and the discussion of the findings are presented in third section, and the last section provides the main findings and summary of conclusions.

II. Materials and Methods

II.1. Materials

Ordinary Portland cement (Type I) conforming to the ASTM requirements was used at a content ranging from 300 to 350 kg/m^3. Crushed limestone coarse aggregate with a maximum size of 25 mm and fine aggregates of clean natural sand are obtained from a local supplier. The fine and coarse aggregates were combined at predetermined ratios. The sieve analysis results are given in Table I. The used aggregate conforms to the ASTM requirements for grading of concrete aggregate [19], Figure 1 shows that the used aggregate falls between ASTM minimum and maximum limits of aggregate.

Drinking water and the Dead Sea water obtained from the Dead Sea's east bank in Jordan were used for the mixing water. A comprehensive chemical analysis to determine the minerals and chloride content of Dead Sea water was conducted in the chemical engineering labs at Al-Balqa Applied University. The ionic species and the composition of the salt, as anhydrous chlorides, are given in Table II. The chemical analysis shows that Dead Sea water is very salty water with an approximate salinity of 32%.

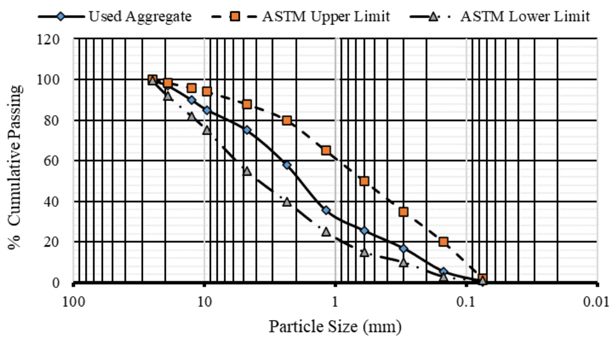

Fig. 1. Grading of the used aggregate compared with the ASTM maximum and minimum grading limits

TABLE I
THE RESULTS OF SIEVE ANALYSIS OF THE USED AGGREGATE

Sieve size (inch)	Sieve Size (mm)	Weight Retained (g)	Cumulative percent passing
1"	25	10	99.5
3/4"	19	50	97
1/2"	12.5	140	90
3/8"	9.5	250	85
# 4	4.75	340	75
# 8	2.36	50	58
# 16	1.18	450	35.5
# 30	0.6	200	25.5
# 50	0.3	175	16.75
# 100	0.15	225	5.5
# 200	0.075	100	0.5
Pan	Pan	10	0
Total		2000	

TABLE II
CHEMICAL COMPOSITION OF DEAD SEA WATER

Ionic species	(g/kg)	Anhydrous chlorides	Weight percentage
Cl^-	184.6	$CaCl_2$	12.5%
Br^-	4.4	KCl	4.4%
SO_4	0.4	$MgCl_2$	51.6%
HCO_3	0.3	NaCl	31.5%
Ca	15.1		
Na	31.5		
K	6.4		
Mg	35.2	PH	6.48

It contains about 21 minerals like potassium, calcium, magnesium, and other 12 minerals which are not found in any sea or ocean water, which makes it unique and very important to know how it affects the concrete and the structures. The salt concentration of the Dead Sea fluctuates around 31.5%. This is unusually high and results in a nominal density of about 1.24 kg/L. Mineral contents of the Dead Sea water vary with season, depth, and temperature. It is clear that the concentration of sulfate ions (SO_4) is very low, and the concentration of bromide ions (Br^-) is the highest compared to all seawaters on earth.

II.2. Methodology

Different concrete mixes were produced by varying the blending ratios (drinking and Dead Sea waters) of mixing water. Five ratios of 0%, 25%, 50%, 75%, and 100% were used in which 0% represents the reference concrete mix produced using only the drinking water and 100% represents the concrete mix produced using Dead Sea water only. Another variable that was investigated is the concrete strength grade. Three concrete grades of cylindrical compressive strength of 25, 30, and 35 MPa (cubic strength of 31, 38, and 44, respectively) were produced by varying the cement content between 300 to 350 kg/m^3 and at a fixed water-to-cement ratio of 0.48.

The mixing and casting procedures followed the standard procedures as described by the ASTM [30]. The compressive strength test was conducted using standard concrete cubes of 150 mm length conforming to the EN-12390-3 standards [31]. The splitting tensile strength was conducted using standard cylinders of 100 mm diameter conforming to the EN-12390-6 standards [32]. Concrete cubes and cylinders were cured and tested at different ages of 7, 14, 28, 56, and 90 days. For each concrete mix and each curing time, three cubes and three cylinders were at least tested, and the average results were recorded. The slump test was conducted for fresh concrete using the standard slump cone test conforming to the EN-12350-2 standards [33] as shown in Figure 2. The air content of fresh concrete mixes was also determined using the conforming to EN 12350-7 standards [34].

III. Results and Discussion

III.1. Effects on Slump Value of Fresh Mixes

The results of the slump test for different concrete strengths are shown in Figure 3.

Fig. 2. Slump test using standard slump cone

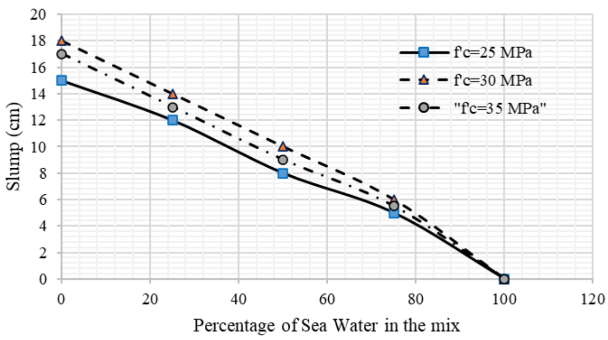

Fig. 3. Slump values for different concrete strengths and percentages of DSW

The slump test results show a significant difference between fresh water and Dead Sea Water (DSW) concrete mixtures. Slump heights in fresh water-based concrete ranged from 150 to 180 mm, suggesting acceptable workability. The usage of DSW, on the other hand, resulted in a zero slump, indicating serious workability issues. The difference is mostly due to DSW's considerably greater viscosity, which results from its higher salt and mineral content as compared to fresh water.

The increasing viscosity of the concrete mixture restricts flow. Furthermore, the mineral content of DSW can disrupt cement binding, reduce cohesive forces within the mix, and limit cementitious matrix production.

Furthermore, the chemical characteristics of DSW can change the hydration process of cement, potentially resulting in the creation of unwanted compounds. As a result, undesirable compounds that impede concrete setting and hardening may form. These findings highlight the importance of carefully selecting the water source for concrete mixing, particularly in areas with access to unique water sources such as the Dead Sea. Water source selection is critical for ensuring workability and performance in a variety of construction applications.

III.2. Effects on Air Content of Fresh Mixes

The results of the air content of fresh concrete mixes are shown in Figure 4. Figure 4 represents the results of the air content of fresh concrete mixes, shedding light on the effect of varying Dead Sea Water (DSW) percentages on this critical parameter. The figure clearly shows a direct relationship between the DSW proportion and the air content in fresh concrete mixes. As the percentage of DSW in the mixes increases, the air content in the concrete samples increases noticeably and consistently. This observed phenomenon is caused by a number of interconnected factors. To begin, the chemical composition of DSW is critical. Because DSW is more saline and mineral-rich than traditional fresh water sources, its incorporation into the concrete mix results in a higher concentration of dissolved ions and minerals.

Entrapped air bubbles, in particular calcium and magnesium ions, may function as nucleation sites for the formation of air voids throughout the concrete. These nucleation sites serve as a starting point for air entrainment, resulting in increasing air content.

Furthermore, the distinct chemical characteristics of DSW can affect the efficiency of air-entraining admixtures used in the production of concrete. These admixtures are commonly used to increase workability and freeze-thaw durability. The efficiency of these admixtures may be reduced in the presence of DSW due to interactions with the high mineral concentration of the water. As a result, air entrainment may be more favored, increasing the air content inside the concrete. In conclusion, the strong association observed between the percentage of DSW and the air content in new concrete mixes emphasizes the complex interaction between water source chemistry and concrete qualities. DSW's high salinity and mineral content enhance the likelihood for air entrainment, resulting in increased air content in the concrete. When DSW is used as a mixing water source, understanding and regulating these impacts is critical for maintaining the appropriate characteristics and durability of concrete. These findings highlight the need of thorough quality control and concrete mix design when using non-traditional water sources in building applications.

III.3. Effects on Density of Concrete

The results of concrete density produced using fresh and Dead Sea waters are illustrated in Figure 5.

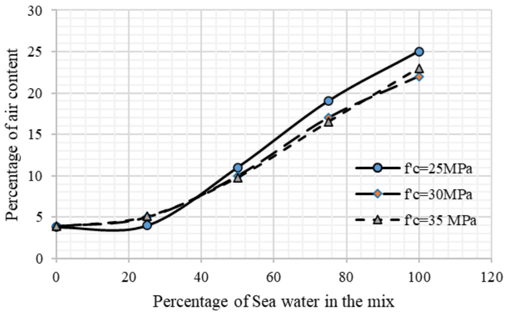

Fig. 4. Air content for different concrete strengths and percentages of DSW

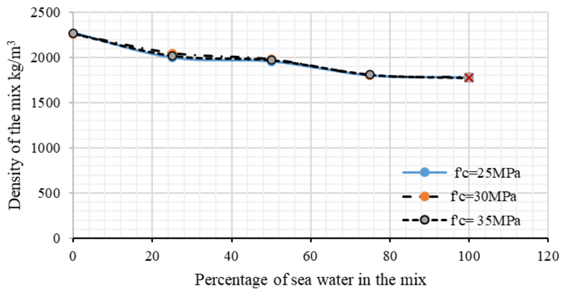

Fig. 5. Density for different concrete strengths and percentages of DSW

This figure demonstrates the concrete density data, which give significant insight into the influence of water supply on the physical qualities of the concrete. The graph clearly illustrates a considerable fall in concrete density when Dead Sea Water (DSW) is used in the mix rather than fresh water. Regardless of the strength of the concrete, the density decreases from 2300 kg/m^3 for fresh water-based concrete to 1800 kg/m^3 for DSW-based concrete. These findings highlight the significant impact of water source selection on concrete characteristics. The increased salt and mineral content of DSW contribute to its lower density, which influences the total mass of the concrete mixture. Table III provides a complete summary of the results for air content, slump values, and concrete density, encompassing the primary results of our investigation. These results illustrate the significance of adopting precaution when selecting water sources for concrete production, particularly in areas where alternative supplies, such as the Dead Sea, are easily available. It is critical for ensuring that concrete has the appropriate properties and performs well in building applications.

TABLE III
SUMMARY OF AIR CONTENT, SLUMP VALUE, AND DENSITY RESULTS

Strength (MPa)	Test	% of DSW in the mix (%)				
		0	25	50	75	100
25	Slump (cm)	15	12	8	5	0
	Air content (%)	3.8	4	11	19	25
	Density (kg/m^3)	2272	2001	1960	1805	1783
30	Slump (cm)	18	14	10	6	0
	Air content (%)	3.9	5	10	17	22
	Density (kg/m^3)	2263	2050	1982	1807	1786
35	Slump (cm)	17	13	9	5.5	0
	Air content (%)	3.9	5.1	9.8	16.5	23
	Density (kg/m^3)	2268	2020	1972	1810	1772

III.4. Effects on Compressive Strength

The prepared standard cubes were tested to determine the concrete compressive strength as shown in Figure 6.

The results of the compressive strength of concrete are given in Table IV and demonstrated in Figures 7, 8, 9, and 10.

The obtained results show a significant variance in the average cube compressive strength of concrete, ranging from 30 to 46 MPa when made with fresh water and significantly decreasing to 4 to 8 MPa when using 100% Dead Sea Water (DSW) in the mix. This significant drop in compressive strength can be related to the presence of chlorides, sulfates, and salts in the DSW composition, which have a significant influence on the complicated process of cement hydration. The significant impact of these chemical components on concrete compressive strength is the consequence of numerous interconnected mechanisms.

Chlorides, for example, may accelerate the corrosion of reinforcing steel within a concrete structure, threatening its structural integrity. Sulfates can also react with the hydrates in hardened cement paste, resulting in the formation of expansive products that cause internal stresses and, as a result, a loss in compressive strength.

Furthermore, high salt concentration might affect the microstructure of the cementitious matrix, preventing correct production of calcium silicate hydrate and modifying the mechanical characteristics of the concrete.

In conclusion, the significant drop in compressive strength seen while utilizing 100% DSW in concrete production emphasizes the negative implications of the Dead Sea water's excessive chloride, sulfate, and salt contents.

These chemical elements have a significant impact on the cement hydration process and, as a result, the structural integrity of the concrete. This result emphasizes the vital relevance of water source selection in concrete production, as well as the need of taking into account the distinctive chemical constitution of alternate water sources such as the Dead Sea. Such aspects are critical for assuring concrete's structural performance and durability in construction applications.

III.5. Effects on Tensile Strength

A thorough testing process is carried out on standard cylindrical specimens to determine the splitting tensile strength of concrete produced with both fresh and salt water.

These typical cylindrical specimens are critical test subjects in our inquiry, which aims to give a full knowledge of how the kind of water supply affects concrete tensile strength. Figure 11 is an example visual presentation that provides a peek of the sampled test cylinders, which are crucial in our experimental study.

These cylinders provide a critical basis for understanding the effects of various water sources on the tensile characteristics of concrete, which is critical in the field of construction materials research and applications.

Fig. 6. Testing of the concrete cube for its compressive strength

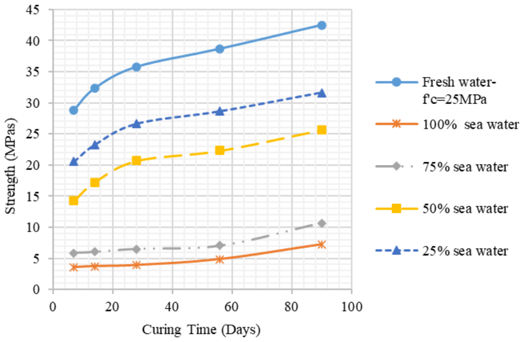

Fig. 7. Concrete compressive strength for different DSW percentages and at different ages

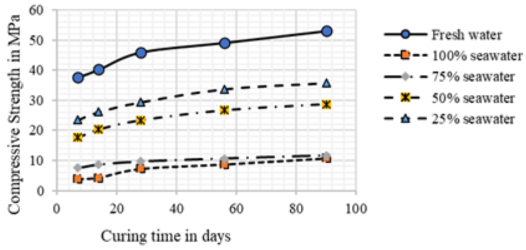

Fig. 8. Concrete compressive strength for different DSW percentage sand at different ages for f´c=30 MPa

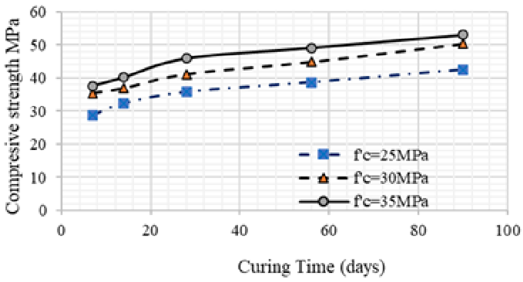

Fig. 9. Concrete compressive strength at different ages

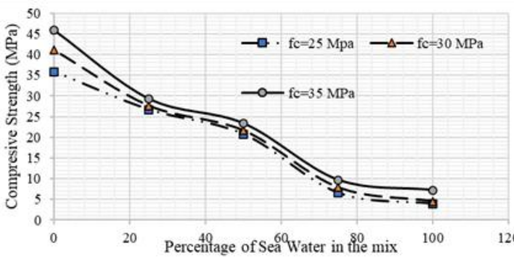

Fig. 10. Concrete compressive strength for different DSW percentages and concrete target strengths at 28 days

Fig. 11. Sample of the tested cylinders
to find the tensile strength of concrete

TABLE IV
SUMMARY OF RESULTS OF CONCRETE COMPRESSIVE STRENGTH

Strength (MPa)	Curing Time (Days)	% of Dead Sea Water in the mix (%)				
		0	100	75	50	25
25 MPa	7	28.866	3.556	5.87	14.254	20.548
	14	32.366	3.717	6.03	17.254	23.254
	28	35.8	3.9	6.512	20.687	26.651
	56	38.7	4.86	7.026	22.325	28.651
	90	42.5	7.26	10.654	25.658	31.652
30 MPa	7	35.4	3.874	6.351	16.874	22.651
	14	36.9	4.357	7.015	18.654	24.365
	28	41.1	4.52	7.861	21.651	27.658
	56	44.8	5.6	7.682	24.651	30.564
	90	50.25	8.7	11.687	27.654	32.6514
35 MPa	7	37.566	3.751	7.514	17.652	23.516
	14	40.2	4.25	8.654	20.369	26.125
	28	45.9	7.2	9.658	23.354	29.325
	56	49.1	8.73	10.651	26.654	33.654
	90	53	10.76	11.651	28.654	35.651

The comprehensive study of these test specimens enables a meticulous examination of the splitting tensile strength in the context of concrete mixtures containing both fresh and salt waters, contributing to a more profound understanding of the materials' performance and potential variations due to the water source used.

The results of the tensile strength of concrete are given in Table V and illustrated in Figures 12 and 13. The results of the experiments show a significant correlation between the proportion of Dead Sea Water (DSW) in the concrete mix and the tensile strength of the final specimens. As the quantity of DSW in the mix grows, the tensile strength of the concrete decreases significantly, by roughly 60%. This significant loss in tensile strength is a direct result of DSW's unusual chemical makeup, which contains high amounts of chlorides and sulfates.

These chemical elements can have a negative influence on the bonding and cohesiveness within the concrete matrix, resulting in a significant decrease in tensile strength.

TABLE V
SUMMARY OF RESULTS OF CONCRETE TENSILE STRENGTH

Compressive Strength	Curing Time (Days)	% of Dead Sea Water in the mix				
		0	25	50	75	100
25 MPa	7	2.012	1.65	0.92	0.65	0.42
	14	2.479	1.95	1.5	0.85	0.72
	28	2.51	2.01	1.62	0.95	0.982
	56	2.72	2.35	1.86	1.52	1.1
	90	2.95	2.56	2.03	1.75	1.32
30 MPa	7	3.96	3.01	2.51	1.53	0
	14	3.27	2.91	2.55	1.6	0.27
	28	3.26	2.95	2.62	1.71	0.45
	56	4.02	3.35	2.85	1.95	0.59
	90	4.37	3.56	2.95	2.01	0.72
35 MPa	7	2.1	1.5	1.3	1.01	0.468
	14	2.2	1.53	1.41	1.02	0.68
	28	2.53	1.85	1.523	1.21	0.74
	56	2.84	2.31	1.852	1.54	0.96
	90	2.97	2.35	1.95	1.65	1.023

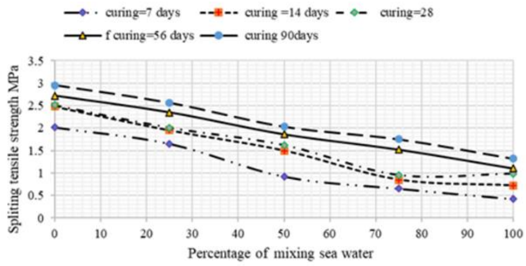

Fig. 12. Splitting tensile strength at different ages

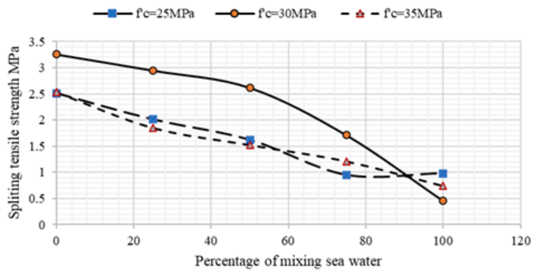

Fig. 13. Splitting tensile strength at 28 days
for different concrete strengths

It is worth noting, however, that tensile strength demonstrates a dynamic response to curing duration.

Specifically, when the curing period is increased, the tensile strength increases. This effect is caused by continuing chemical reactions inside the concrete matrix as it strengthens over time. The curing process promotes the growth of hydration products, resulting in stronger linkages and a denser microstructure. As a result, the tensile strength of the concrete specimens is increased.

The interaction between curing time and tensile strength emphasizes the importance of both time and the curing environment in the overall development of mechanical properties in concrete, providing valuable insights for optimizing the performance and durability of concrete mixtures in practical construction applications.

IV. Conclusion

In summary, the main objectives of this experimental study were to thoroughly investigate the implications of using Dead Sea water (DSW) as a mixing agent in concrete production, as well as to assess the mechanical and physical properties of concrete mixed with DSW, such as concrete density, air content, and compressive and tensile strengths. The results of this study give important insights into the practical application of DSW in the construction sector, as well as its potential as a sustainable alternative to freshwater. Several significant conclusions may be taken from the research results:

- *Chemical Composition of Dead Sea Water:* Chemical examination of Dead Sea water has indisputably proven its extraordinarily high salinity, with a stunning salinity level of 32%, which makes it the saltiest water source on Earth. This severe salinity is a distinguishing feature of Dead Sea water, distinguishing it from other sources of water and substantially altering its interactions with concrete.
- *Air Voids Ratio and Dead Sea Water:* This research has shown that using Dead Sea water into concrete mixes increases the air voids content by roughly 20%. These air gaps, caused by the peculiar chemical composition of Dead Sea water, have a substantial influence on the physical qualities of the concrete, such as density and porosity.
- *Slump Test and Workability:* The slump test results for fresh concrete indicate the influence of Dead Sea water content on the mixture's workability. The slump values consistently decrease as the proportion of Dead Sea water in the mix increases. This workability issue is mostly due to the viscosity of Dead Sea water, which impedes the flow and deformability of the concrete mix.
- *Density Reduction and Hydration Effects:* Concrete combined with Dead Sea water has a 17% lower density than concrete mixed with fresh water. This drop is mostly due to the increased air voids content, resulting in the concrete more porous. Furthermore, the hydration of cement in the presence of Dead Sea water is hampered by high chloride and sulfate concentrations, affecting the overall density and durability of the concrete.
- *Compressive Strength Effects:* As the quantity of Dead Sea water in the mix increases, the compressive strength of concrete decreases gradually, with losses ranging from 30% to 85%. The decrease in compressive strength illustrates the negative impact of Dead Sea water's specific composition on the structural integrity of the concrete.
- *Splitting Tensile Strength Effects:* Similarly, as the quantity of Dead Sea water in the mix increases, the splitting tensile strength of concrete decreases gradually, ranging from 15% to 75%. The unusual chemical elements of Dead Sea water have a significant influence on the capacity of concrete to resist tensile pressures, reflecting the problems of using this water source in the production of concrete.
- *Overall Implications:* This research results show the major effect of Dead Sea water on several concrete qualities such as workability, density, and mechanical strengths. These findings are critical for directing building practices in areas where Dead Sea water may be used as a supply of water, stressing the significance of careful planning and specialized concrete mix designs to achieve desired performance and durability.
- *Future research options* for adding Dead Sea water into concrete include a variety of potential avenues. These include the research and development of alternate materials for construction and additives to mitigate the negative impacts of excessive salinity and mineral content, as well as the investigation of novel curing procedures and chemicals. In-depth research on the chemical compatibility of Dead Sea water and cementitious materials can give important insights into the mechanisms influencing concrete strength. Furthermore, research efforts might concentrate on enhanced water treatment technologies to minimize salinity, long-term durability studies, and environmental effect analysis. Evaluating alternate water sources and taking regional and socioeconomic effects into account will also be necessary, as will the formulation of specialized building rules. Finally, case studies and field testing will provide practical insights into the real-world performance of Dead Sea water-based concrete constructions. These study paths aim to improve our understanding of the problems and possibilities linked with Dead Sea water usage in construction industries.

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