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Effect of Using Dry Sludge (DS) of Water Purification in Combination with Treated Wastewater (TWW) on Concrete Strength

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Abstract The construction industries utilize large amount of fresh water. Water used in the construction industry is not for only mixing concrete; it is also used for equipment cleaning, washing aggregate, and curing concrete. The social and economic cost of the scarce source of water in many parts of the world makes it significant to look for lower quality water to be used in concrete production. The water must meet certain quality requirements to be suitable for concrete mixing and curing. It has been found that certain water that does not meet high quality can be used in making concrete of acceptable quality. The short and long effects of using low quality water on concrete mechanical properties have been investigated in different parts of the world. Combining the use of recycled materials and low quality water in concrete mix could increase the deterioration of mechanical properties of hardened concrete. In this paper, the effect on compressive strength of hardened concrete using treated wastewater (TWW) and dry sludge (DS) produced by water purification facilities in concrete mixes to substitute potable water (PW) and fine aggregate. The TWW is used to substitute PW in ratios between 30 and 100% while DS is used in ratios of 10 to 30% of fine aggregate. Different design mixes are prepared and standard concrete samples are cast and tested to report the changes in compressive strength due to alteration of the standard concrete mix. Results show that using TWW only reduced the compressive strength of concrete by about 11 % while using DS in combination with TWW reduced the compressive strength by a percentage reached 26%. The use of recycled materials will affect the concrete quality with acceptable values. Utilizing these recycled materials on concrete mix will save environment and release part of the pressure on scarce sources such as water in semi-arid regions.

Keywords Dry Sludge (DS), Treated Wastewater (TWW), Concrete, Compressive Strength

1. Introduction

The concrete constructions are growing very fast in all parts of the globe where about 3.0 tons per capita of concrete are produced by the construction industry every year. Every 1m^3 of concrete requires about 150 liters of water [1]. Water is used in the construction industry for more than only mixing concrete; it is also used for equipment cleaning, washing aggregate, and curing concrete. In order to produce concrete with high strength and good durability, the quality of the water used for mixing and curing is crucial [2–5]. The primary issue with the concrete industry is not just the usage of fresh water; it also involves air pollution, large-scale natural resource consumption, high energy needs, demolition waste, water consumption, and construction waste production [6,7]. The use of treated wastewater or recycled water in place of fresh water can help to keep fresh water in the cycle for more critical uses. Additionally, using treated effluent can lessen and manage environmental harm [8].

The water must meet certain requirements to be suitable for batching with fresh concrete, such as being safe and devoid of harmful substances. These conditions, however, cannot be the best standard for judging whether water is appropriate for use as a mixing medium. It has been discovered that certain water that does not adhere to these guidelines can nonetheless produce concrete that is of acceptable quality [9-15]. The amount of soluble sulfates in the mixing water is crucial since it will impact how well an individual is hydrated [16,17].

In the literature, there are several contributions from researchers in this area. The published research includes a wide range of topics, including examining how employing wastewater affects the qualities of cement paste, fresh concrete, and hardened concrete, particularly strength [5,9,16-27].

Focus is placed on compressive strength when discussing the qualities of hardened concrete, according to ASTM C94 [2,28]. It is recommended that the 7 days compressive strength of standard mortar cubes made with treated water should not be less than 90% of that made with tap water. The specifications do not contain any requirements for flexural strength [2, 3,6].

Concrete has a variety of mechanical characteristics, including compressive strength, durability, performance, and permeability [28,29], each of which has a specific significance and can be identified as the primary requirement for using concrete based on the type of work [30,31]. However, compressive strength is typically regarded as the most crucial aspect of any concrete [32-34].

The results of studies on the impact of using treated wastewater on concrete on hardened concrete strength range from increasing concrete strength as in [18], having no significant effect as in [19], and diminishing compressive strength as in [20,21].

The use of recycled materials other than water as a subsidy for filling aggregates and cement is another area of research to reduce the environmental impact of the concrete industry. The effects of building demolition waste and non-organic industrial waste on the mechanical properties of hardened concrete have been extensively studied, as seen in [14,30,31,35].

In this study, secondary treated wastewater (TWW) from wastewater treatment plant and dry sludge (DS) from water treatment plant are used in Grade M20 concrete mix that is suitable for ordinary concrete construction where the 7 days and 28 days concrete strength is tested using different treatments.

2. Materials and Methods

Materials employed in this study include the common concrete mix, which contains potable water (PW), ordinary Portland cement (OPC), fine aggregate with a specific gravity of 2.65 and sizes ranging from 0.5 to 2 mm, and coarse aggregate with a specific gravity of 2.54 and sizes ranging from 5 to 15 mm. The concrete compositions don't contain any admixtures.

Different ratios of secondary treated wastewater (TWW) are used in place of PW. Regarding the organic matter, sulfate, and alkalinity, the TWW utilized for concrete mixes is of acceptable grade [2,36].

Dry sludge (DS) from water treatment plant is used as a substitute for fine aggregate. The water purification plant treats water from rainfall floods using coagulation and flocculation process to remove suspended solids from water and the resulting waste is the sludge that is dried for reuse or dumping in waste pits. The specific gravity of the dry sludge used is about 1.71. The main concern of DS usage is the organic content, the DS used in this study has 1.8% organic content which is acceptable for concrete mixes [2].

The chosen concrete mix design, 1:1.5:3, is advised for M20 concrete [37]. Table 1 gives the weights of the various mix contents to have roughly 50 kg of fresh concrete, which is adequate to construct 6 standard cube samples (150 x 150 x 150 mm) for each treatment. Since there are no admixtures employed, the w/c ratio of 0.5 is used to have good workability. The cubes were made and cured in accordance with JS 1652-2:2004 [38]. The cubes are tested after 7 and 28 days for 3 cubes each time.

Table 1. Mix design for reference concrete design

Material	Weight (kg)
Water	4.2
Cement	8.4
Fine aggregate	12.6
Coarse aggregate	25.2

Potable water (PW), cement, fine aggregate, and coarse aggregate are used to create a control mix sample according to Table 1. Three mix groups are prepared using recycled materials (TWW and DS). In the first, group (Group-A), TWW is used to substitute the PW at three ratios: 30, 60 and 100%. The weights for different material contents in the three replicates are listed in Table 2. In the second mix group (Group-B), DS is used to substitute the sand at ratios of 10, 20, and 30% while using PW. The weights for different material contents in these three replicates are listed in Table 3. In the final mix group (Group-C), sand is substituted by 10, 20, and 30% DS, while water used is split 50/50 between PW and TWW as listed in Table 4 for the three replicates.

Table 2. Mix designs using TWW as a substitute of PW

Material		Weights in each treatment (Kg)		
		A-1	A-2	A-3
Water	PW	2.94	1.68	0
	TWW	1.26	2.52	4.2
Cement		8.4	8.4	8.4
Fine Aggregate (sand)		12.6	12.6	12.6
Coarse Aggregate		25.2	25.2	25.2

Table 3. Mix designs using DS as a substitute of sand in the fine aggregate

Material		Weights in each treatment (Kg)		
		B-1	B-2	B-3
Water (PW)		4.20	4.20	4.20
Cement		8.40	8.40	8.40
Fine Aggregate	Sand	11.34	10.08	8.82
	DS	1.26	2.52	3.87
Coarse Aggregate		25.2	25.2	25.2

Table 4. Mix designs using DS as a substitute of sand in the fine aggregate in combination of using 50/50 TWW/PW

Material		Weights in each treatment (Kg)		
		C-1	C-2	C-3
Water	PW	2.1	2.1	2.1
	TWW	2.1	2.1	2.1
Cement		8.40	8.40	8.40
Fine Aggregate	Sand	11.34	10.08	8.82
	DS	1.26	2.52	3.87
Coarse Aggregate		25.2	25.2	25.2

3. Results and Discussion

The different concrete mixes are prepared and mixed then molded in the standard molds using 6 molds for each treatment. After 24 hours the cubes are taken out of the molds and cured in PW until the test dates. After 7 days, three cubes from each treatment are tested using uniaxial load and the familiar loads are recorded and averaged for each treatment. The compressive strength was then calculated for each treatment. The other 3 cubes for each treatment are left in water until 28 days and tested for strength in the same way.

The average strength for each treatment is tabulated and compared to the control mix. Table 5 and Figure 1 show the results for Group A treatments where TWW is used to substitute PW in ratios of 30, 60 and 100% in the mixing water. The results show that the compressive strength in the mixes that used TWW is lower than the control that used PW but the difference is about 11% on average. This reduction is acceptable and compromised by reusing TWW.

The cubes for treatments in the second group, Group B are cured and tested in the same way 3 after 7 days and 3 after 28 days. In these treatments, the dry sludge from water purification facility is used to partially substitute the sand as fine aggregate at ratios of 10, 20 and 30 %. The results for these mixes show a significant reduction in compressive strength as listed in Table 6 and shown in Figure 2. The reduction varied from 7.3% when using DS as only 10% of the fine aggregate to 20.4% for higher DS portion (30%). These results might be because of the nature of DS which is the result of coagulation and flocculation water treatment process that accumulate the suspended solids in water using a physio-chemical process. The result of this process is a material that has a relatively low specific gravity (1.71) and a crispy texture.

In Group C treatments, the water used is 50% PW and 50% TWW while the sand as fine aggregate is substituted by DS. The results for these mix treatments show a large reduction in the compressive strength as shown in Table 7 and Figure 3. The reduction in compressive strength is more than 20%. This is expected when using a combination of more than one recycled material that has effects on compressive strength due to the constituents of these materials. The TWW might have some chemicals such as organic matters that have a negative effect on cement hydration and strength. Also, the DS texture and possibly chemical constituents form a weakness point in the concrete texture and accelerate the failure of it.

Table 5. Compressive strength results for Group A treatments

Treatment	Compressive strength (MPa)		Reduction % in 28 strength
	7 days	28 days	
Control	16.79	25.09	-
A-1 (30% TWW)	14.22	22.72	9.4
A-2 (60% TWW)	15.55	21.91	12.7
A-3 (100% TWW)	14.81	22.28	11.2

Table 6. Compressive strength results for Group B treatments

Treatment	Compressive strength (MPa)		Reduction % in 28 strength
	7 days	28 days	
Control (0% DS)	16.79	25.09	-
B-1 (10% DS)	14.74	23.27	7.3
B-2 (20% DS)	13.64	21.27	15.2
B-3 (30% DS)	13.23	19.96	20.4

Table 7. Compressive strength results for Group C treatments

Treatments	Compressive strength (MPa)		Reduction % in 28 strength
	7 days	28 days	
Control (0% DS) (0% TWW)	16.79	25.09	-
C-1 (10% DS) (50% TWW)	13.84	20.31	19.1
C-2 (20% DS) (50% TWW)	11.11	18.52	26.2
C-3 (30% DS) (50% TWW)	12.68	19.47	22.4

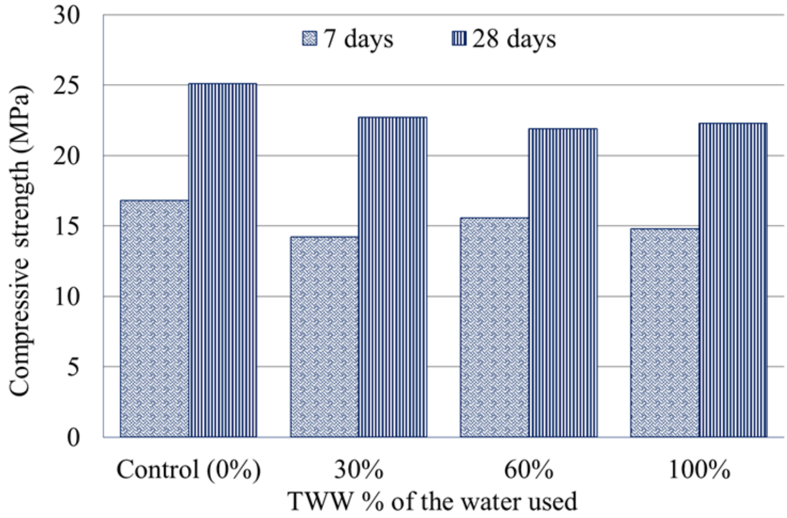

Figure 1. Compressive strength results for Group A treatments

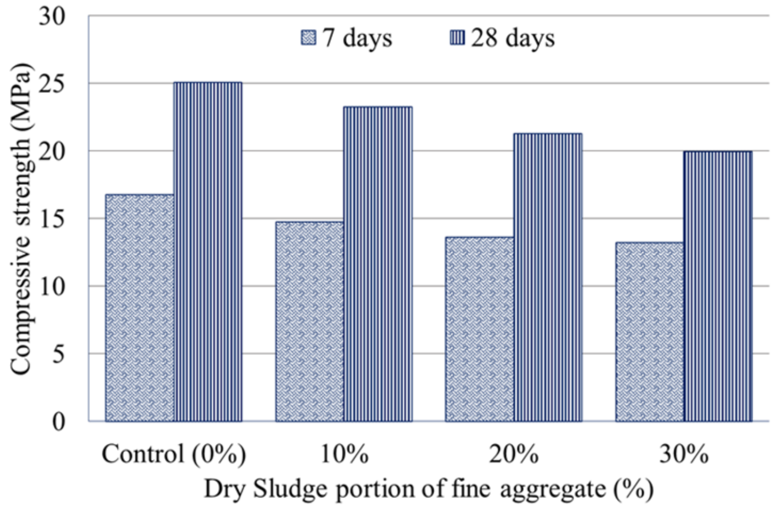

Figure 2. Compressive strength results for Group B treatments

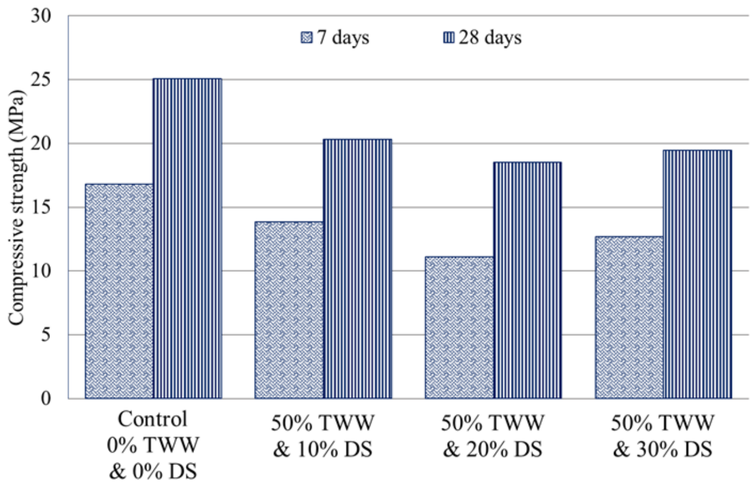

Figure 3. Compressive strength results for Group C treatments

4. Conclusions

Using treated wastewater in concrete mixes is a promising alternative to save precious fresh water in areas that suffer from the scarcity of fresh water such as Jordan. Even though using water with lower quality might affect the mechanical properties of concrete mainly the compressive strength, it could be used in low grade concrete mixes where they don't have a major role in the structure's strength. Another area of environmental sustainability is the use of the byproducts of water purification such as sludge in concrete. The use of dry sludge as substitute of sand will have a positive environmental effect by recycling the sludge and saving energy to utilize natural materials for concrete mix.

Different components of cement react in different ways with impurities in water or mixing materials. These interactions primarily have an impact on the setting time and compressive strength of concrete, and they can eventually lead to concrete deterioration. Certain contaminants react in a way that makes the final product more durable or with better concrete qualities. Moreover, the chemical makeup of recycled materials varies based on the location, the season, the environment, and human intervention. In light of this, it is challenging to reach a consensus about the usage of treated wastewater and recycled materials in concrete mixing.

Following are the main conclusions and recommendations that can be derived from the results of this research:

1. Using TWW in the concrete mix has a limited effect on concrete strength and can be used in low to medium grade concrete where the reduction on concrete strength is limited.
2. Using DS as part of the fine aggregate does not have a major reduction in the compressive strength of concrete but caution needs to be considered when used in high grade concrete mixes since its long-term effect on concrete is not clear. The physical-chemical structure of dry sludge could influence its reaction to cement and response to mechanical forces.
3. It is recommended that the effect of using DS in cement mortar is studied and also its use in light weight concrete because of its low specific gravity.

Early strength effects of using recycled materials and reclaimed water in concrete mixing are thought to be modest. Yet, the common assumption is that concrete's long-term strength will decline and its durability will be low. In the same context, reinforced concrete has a risk of steel corrosion, which is a significant area of study interest.

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