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Reuse of Wastewater Treatment in Cement Mortar

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--***ABSTRACT***--
This paper study of the effect of using treated wastewater on cement mortar and masonry walls, the potable water is considered scarce in many of the world's countries, and finding applications for treated wastewater reuse is very effective in preserving potable water resources. Therefore, an experimental program consisting of three phases was developed. The aim of first phase is to evaluation of the chemical and mechanical properties of the materials used in the specimens. The second phase includes testing of mortar cubes made from potable water and mortar made from secondary treated wastewater, according to the Egyptian code for designing and executing masonry works. The third phase is studied masonry prisms' using two types of mortar is mentioned above, where tests were conducted (compressive strength, shear strength, in plane tensile strength, flexural tensile strength for out of plan bending). The results showed minor change for strength prisms values, which constructed by using mortar made from secondary treated wastewater compared to prisms constructed by using mortar made from potable water.
KEYWORDS;- *Treated Wastewater, Mortar, Axial compressive strength, Shear Strength, In-Plane tensile strength, Out-of-Plane tensile strength.*

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I. INTRODUCTION

Recently many wastewater treatment plants were established in Egypt. One potential reuse will be in the production of cement mortar for masonry walls and plastering work. The construction industry is consuming one billion cubic meters of mixing water. In addition, enormous quantities of fresh water is used for washing of the mixer trucks concrete pumps, equipment, aggregate, curing concrete and ready mix concrete [1, 2, 3]. Currently, the construction industry in Egypt is consuming approximately 10 MCM/year of fresh water. Demand for construction industry dramatically increased with a commensurate increase in concrete industry demand. Egypt's population has doubled during the last 20 years due to natural growth. Given the growing and competing demands for freshwater in Egypt and other growing, water-scarce regions, it is necessary and prudent to conduct research on the feasibility of substituting fresh water with lesser quality water, such as treated wastewater, in the construction industry [4, 5, 6]. Therefore, this research is an attempt to solve the problem of wastewater by using the wastewater as a partial replacement for fresh water in the production of ready mix cement mortar. The reuse of treated wastewater in cement mortar industry will contribute to the sustainability and better management of both the water sector and construction industry at the same time. Substantial quantities of potable water, saved for construction industry, will be available for domestic use. The experimental program was conducted on 24 masonry specimens. Small-scale axial compression, shear, in plane and out of plane bending test was carried out on specimens comprising of brick masonry walls. The reference wall specimen was made by cement mortar using fresh water (tap water). Other wall specimens were made by cement mortar using treated wastewater in replacement of fresh water. This paper has as the main objective to reuse of wastewater treatment in cement mortar in masonry walls.

II. EXPERIMENTAL PROGRAM

This paper discusses the possibility of reuse treated wastewater in cement mortar and masonry walls work. The experimental program of the current research work consists of masonry prisms. The materials used in prisms are cement, sand, tap water (TW), Secondary treated wastewater (STWW), and bricks. Masonry prisms were tested according to the available national specifications. In this paper, two types of mortar were tested.
Two type of masonry walls are study here, the experimental work is shown in Table 3.1
Masonry walls made with cement mortar made from tap water (TW).
Masonry walls made with cement mortar made from secondary treated wastewater (STWW).

Test		Samples dimensions (cm)			
		Length (cm)	Width (cm)	Height (cm)	number
Axial compression test		20	10	35	6
Shear strength test		30	10	30	6
In-plane tensile strength test	θ =0°	40	10	30	6
	θ =90°	30	10	40	6
	θ =45°	40	10	30	6
Flexural tensile strength for out of plane test	Tension normal to bed joint	35	60	6	6
	Tension parallel to bed joint	80	20	6	6

Table 1: Experimental work

Mechanical properties of bricks

Bricks should be uniform in color, shape, and size; in the experimental program, clay bricks were used. The standard size of the bricks must be preserved. Two brick factories have been selected (DAHAB, ELARAB). The mechanical Properties of bricks had been determined by carrying out tests such as (compressive strength test and absorption test). The tests were carried out according to the Egyptian code for the tests as follows:

The absorption test

The brick units were placed in water for 24 hours, then weighted, and then dry it in the oven to re-weight it, and the percentage of the unit absorption was calculated from below equation:
Absorption (%) = ((Y-X) / X) *100
Y = Weight the brick after submerged in water for 24 hours (Kg).
X = Weight the brick after drying in the oven (Kg).
The average absorption percentage ratio for DAHAB and ELARAB is (7.28%, 6.69 %) respectively.

The compressive strength test

The compressive strength must be determined to establish the quality of the masonry units. The units were capped with wood at top and bottom to achieve uniform load on the bearing surface. Testing machine in the properties and strength of material laboratory, Mataria, Helwan, Egypt. The axial compression strength of the units were calculated from divided the failure load by the area and then calculated the average compressive strength. Average compressive strength for DAHAB and ELARAB (4.60, 4.66 MPA) respectively.

Properties of mortar

The initial purpose of the cement mortar is to fill the voids between the masonry units. It also add strength to masonry and provide resistance to penetration of light, wind, water as well as bond the units together. In addition, the purpose of mortar is to transfer the gravitational force uniformly through the block, the tying effect being achieved by friction and the staggered pattern of the blocks. The strength of the mortar effects the strength of the masonry in compression, tension and flexure. According to the Egyptian Code for designing and executing masonry works, two types of mortar were tested; mortar made from potable water and mortar made from treated wastewater. The experimental mortar samples of both water from potable water and treated waste water will testing at the lab and compare between the results after 1, 3, 7, and 28 days. The compression test for cubes of mortar made from potable water and mortar made from secondary treated waste water has been performed. The average compressive strengths of tested mortars after 1, 3,7 and 28 days for mortar made from potable water and mortar made from secondary treated wastewater was (2 and 3) N/mm^2, (4 and 4.5) N/mm^2, (12.5 and 13) N/mm^2, (20.6 and 20.9) N/mm^2 respectively.

Properties of masonry

Masonry is a composite material composed of units and mortar, so we will measure the interaction of these materials as prisms to determine the characteristics of masonry, where these tests for masonry will be as axial compression test, shear strength test, flexural Tensile strength test and in plane strength test. The procedures of these tests are as follows.

Axial compression test

Compression tests of masonry prisms are used as the basis for assigning design stress and, in some cases, as a quality control measure. Its importance has made prism compressive behavior a major research focus and potential correlation with other strength characteristics have been investigated .Test machine capacity and specimen height limits as well as other practical considerations have led to use of prisms as the main type of compression test specimen rather than full-scale specimen. There are variable factors that affect the prism compressive strength; these factors include the prism capping, prism shape, type of masonry bond, unit strength, mortar type, mortar strength, the joint thickness and workmanship. In this research, the compressive prism consisted of five brick units, including mortar bedding of 10 mm thickness, Since the mechanism of this test was to transfer the load from the top to the bottom of the prism so it was necessary to make a capping from the gypsum to provide a flat surface that allows uniform distribution of the load on the loaded area. The masonry prisms have been constructed using two different types of mortar: cement mortar made from (PW) and cement mortar made from (STWW) as shown in Figure1.

a. Prism constructed using mortar TW.

b. Prism constructed using mortar STWW.

Fig. 1: Samples of prisms under axial compression test before testing.

Shear test

Masonry shear walls were intended to resist shear forces due to in-plane lateral loads plus to the effect of axial load and bending. Test to measure the shear strength along mortar bed joints have not been standardized, and as a result, many variations have been developed. Some types of tests that have been used: triplet, modified triplet, couplet and off-axis compression. Therefore, in this research the triplet type has been carried out as shown in Figure2. The shear stresses at failure were calculated using the following formula

$$\tau = P/A$$

where:

τ = shear stresses P = failure load A = net area of contact between the two blocks

a. Prism constructed using mortar TW.

b. Prism constructed using mortar STWW.

Fig. 2: Samples of prisms under shear test before testing.

In – Plane Tensile Strength

In load bearing masonry buildings, shear walls carry vertical loads and resist the lateral in-plane loads due to wind or earthquakes. This combined loading creates principal tension stresses in the wall leading to tensile cracking when the tensile strength of the masonry was exceeded. The splitting tension test has been very useful for developing an understanding of the factors affecting in-plane tensile strength of masonry. Factors affecting in-plane tensile strength such as:

1- Orientation of the principal tension stress.
2- Mortar type.
3- Strength of masonry unit.

Where the splitting tensile strength determined from the following equations:

F_t = P/A *when* θ = 90° F_t = 0707P/A *when* θ = 45° F_t = 2P/A *when* $\theta = 0°$

a. Prism constructed using mortar TW. b. Prism constructed using mortar STWW.

Fig. 3: Samples of prisms under in-plan splitting tensile test with $\theta = 0°$.

a. Prism constructed using mortar TW. b. Prism constructed using mortar STWW.

Fig. 4: Samples of prisms under in-plan splitting tensile test with θ = 90°

a. Prism constructed using mortar TW. b. Prism constructed using mortar STWW.

Fig. 5: Samples of under in-plan splitting tensile test with θ = 45°

Out – of Plane Tensile Strength

The flexural tensile strength of masonry for out of plane tensile strength relates to the resistance of walls subject to lateral loads from wind, earthquake, or earth pressure, and to eccentric load or direct bending due to gravity loading. Flexural tensile strength is usually referred to in terms of direction of the tension, that is, either normal to the bed joints, *f''m*, or parallel to the bed joints, *f'tp*.

Where the flexural tensile strength determined from the following relation:

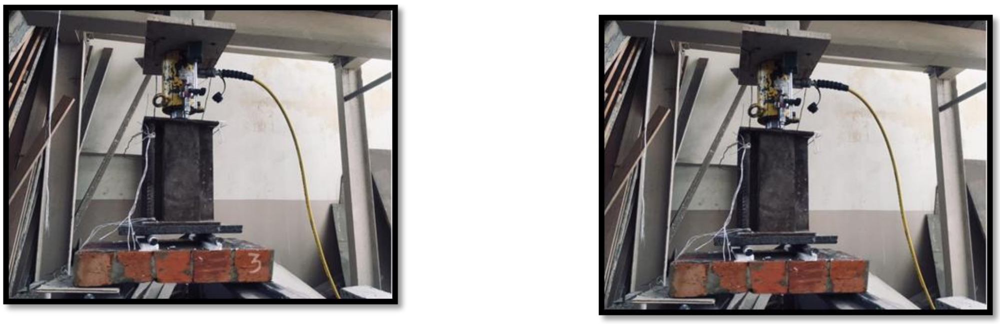
f't → Flexural tensile strength *M* → Bending moment *I* → Moment of Inertia

Out – of Plane (Tension normal to bed joints)

The method used in this research to determine the flexural tensile strength in this case was ASTM E518. , where this method uses beam tests of stack-bonded prisms with prisms heights at least 450mm and either third-point loading, as shown in Figure 6.

Out – of Plane (Tension parallel to bed joints)

The test methods were developed to determine tensile bend strength normal to the bed joints. However, with some modification, researchers have adopted them to tests for tension parallel to bed joints. For the prism beam tests, the length parallel to the bed joints must usually be at least four units, as shown in Figure 7.



a. Prism constructed using mortar TW. b. Prism constructed using mortar STWW.

Fig. 6: Prisms under tests for flexural tension normal to bed joints.

a. Prism constructed using mortar TW. b. Prism constructed using mortar STWW.

Fig. 7: Prisms under tests for flexural tension parallel to bed joints.

III. EXPERIMENTAL TEST RESULTS

The test results of axial compression test, shear strength test, in-plane tensile strength and out of plane tensile strength as mentioned following.

Axial compressive test

The failure modes for samples were a shear compression failure as shown in Figure 8. Vertical cracking were formed along the height of the masonry units , these cracks is vertically in bricks because of the lateral tensile stresses in the bricks and then followed by cracks in the bed joints of mortar by increasing the vertical load, samples were constructed by using mortar made from (STWW) have higher resistance to axial compression than samples were constructed by using mortar made from (TW) because the strength of mortar had affected on the compressive strength of assemblages. There was no significant difference in axial compressive strength of masonry prisms between masonry prisms made of potable water versus secondary wastewater plant ass shown in Figure 9.

a. Prism constructed using mortar PW. b. Prism constructed using mortar STWW.

Fig .8: Failure mode of masonry prisms under axial compression test.

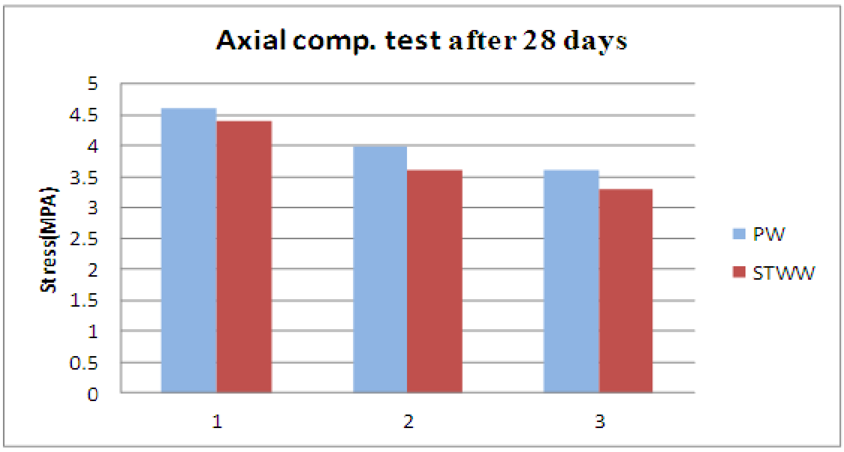


Fig. 9: Axial compressive stress values (28days).

Shear strength test

The real mode of failures of the prisms, which the joint slip failure normally occurs along the interface between the mortar and the unit for both types of mortar. As shown in figure 10. The average shear strength of the prisms were constructed by using mortar made from (TW) and mortar made from (STWW) was (1.72 and 2.20) N/mm^2 respectively. From results, it can be inferred that samples were constructed by using mortar made from (STWW) have a higher shear resistance than samples constructed by using mortar made from (TW) because the shear strength of assemblages affected by the contact area between the mortar and block interface. The shear strengths obtained for masonry walls made with tap water or secondary treated wastewater are equal 0.3 N/mm^2 as shown in Table 2.

a. Prism constructed using mortar PW.

b. Prism constructed using mortar STWW.

Fig. 10: Failure mode of masonry prisms under shear test.

Samples	Area (mm²)	Failure load (kN)	Shear strength (N/mm²)	Average shear strength (N/mm²)
Prisms constructed using mortar with (TW)	18000	5.2	0.30	0.30
	18000	6.0	0.30	
	18000	7.8	0.40	
Prisms constructed using mortar with (STWW)	18000	6.0	0.30	0.30
	18000	4.8	0.30	
	18000	6.5	0.40	

Table 2: Failure loads and shear strength values.

In plane tensile strength

To carry out this test three samples were constructed by using mortar made from (TW) and another three samples were constructed by using mortar made from (STWW) have been constructed in each case of load.

In case of line loads normal to the bed joints

In case of the line loads normal to the bed joints, the cracks started along the block then it moved along the block and the mortar interface at the head joint in case of assemblages were constructed by using mortar made from (TW) and using mortar with (STWW) , cracks in the assemblages made from (TW) occurred at loads (132, 129 and 127.5) kN respectively and cracks occurred in the assemblages made from (STWW) at loads (145, 136 and 131.1) kN respectively as shown in Figure11, and the average in plane tensile strength in this case of loading for prisms were constructing by using mortar made from (TW)and mortar made from (STWW) was (7.05 and 7.49) N/mm2 respectively. So, the samples were constructed by using mortar made from STWW have higher resistance to splitting tensile than the samples constructed by using mortar made from in case of splitting tension parallel to bed joints and the Comparison between stress for masonry prisms constructed by using mortar made from (TW and STWW) under in-plan tensile strength test at θ = 0 shown in Figure 12.

a. Prism constructed using mortar PW.

b. Prism constructed using mortar STWW.

Fig. 11: Failure mode of prisms under in-plan splitting tensile test with θ = 0°

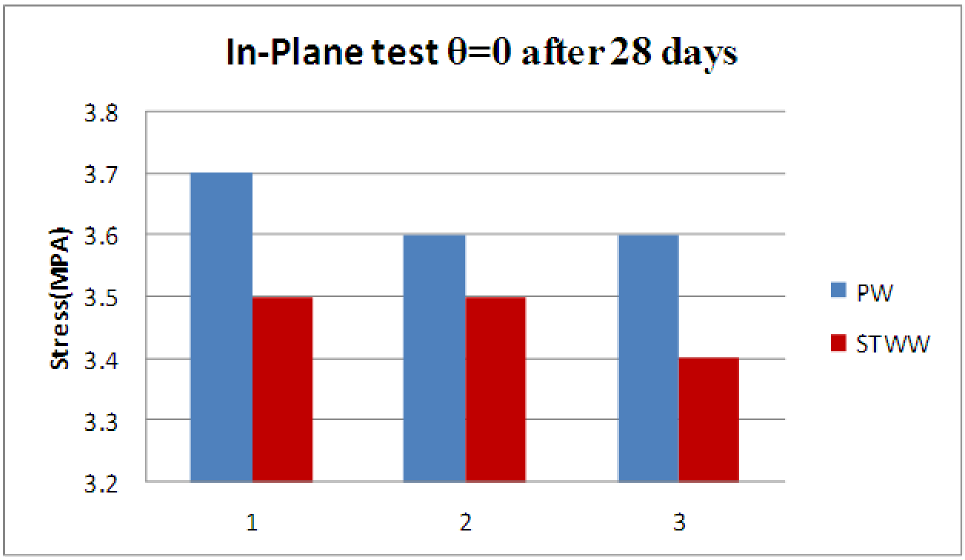
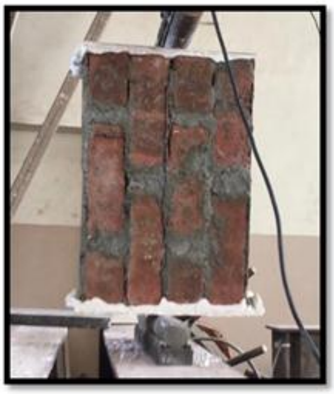


Fig. 12: Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 0.

In case of line loads parallel to the bed joints

In case of line loads parallel to the bed joints, the cracks started along the block and the mortar interface at the bed joints and then passing through it only in both cases of assemblages were constructed by using mortar made from (TW) and assemblages were constructed by using mortar made from (STWW).failure cracks in the assemblages were constructed by using mortar made from (TW) occurred at loads (6.36, 7.1 and 8.1) kN respectively, while failure cracks occurred in the assemblages were constructed by using mortar made from (STWW) at loads (6, 7 and 9.6) kN respectively as shown in Figure 13, and the average in- plan tensile strength in this case of loading of prisms were constructed by using mortar made from PW and mortar made from STWW was (0.27 and 0.28) N/mm^2 respectively, it can be conclude that the samples were constructed by using mortar made from (STWW) have higher resistance to splitting tensile than the samples constructed by using mortar made from (TW) in case of splitting tension normal to bed joints. And the comparison between stress for masonry prisms constructed by using mortar made from (TW and STWW) under in-plan tensile strength test at θ = 90 shown at Figure 14.

a. Prism constructed using mortar PW.



b. Prism constructed using mortar STWW.

Fig. 13: Failure mode of prisms under in-plan splitting tensile test with θ = 90°

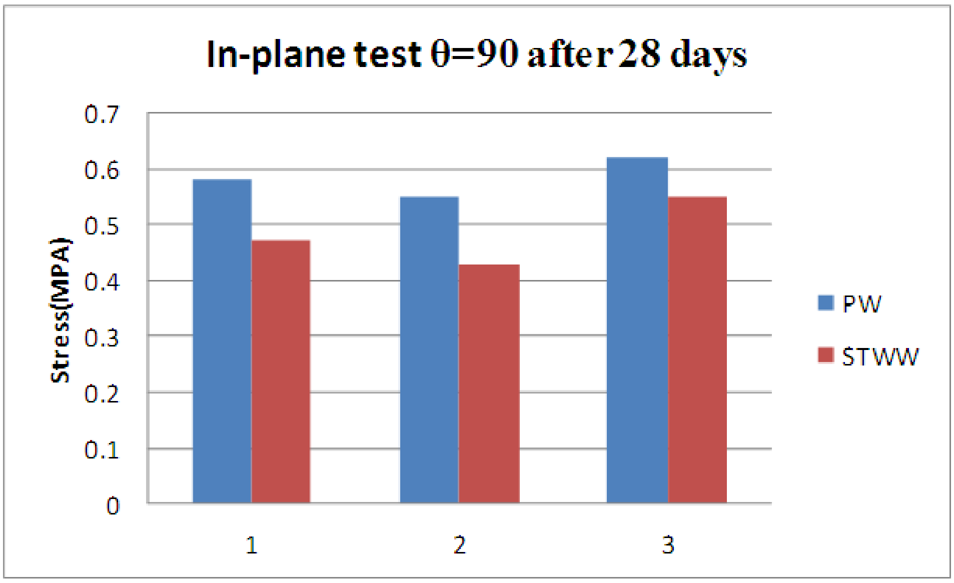


Fig. 14: Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 90.

In case of line loads oriented at 45° from the bed joints

In case of line loads oriented at 45° from the bed joints the cracks started along the block and the mortar interface at the head joints and passing through the block and the mortar interface at the bed joints in both cases of assemblages were constructed by using mortar made from (TW) and assemblages were constructed by using mortar made from (STWW). Failure cracks in the assemblages were constructed by using mortar made from (TW) occurred at loads (16.7, 19.5 and 25.5) kN respectively, while failure cracks occurred in the assemblages were constructed by using mortar made from (STWW) at loads (10.34, 16.76 and 17.95) kN respectively as shown in Figure 15. The average in plane tensile strength in this case of loading of prisms were constructed by using mortar made from (TW) and mortar made from (STWW) was (1.59 and 1.14) N/mm^2 respectively. So, the samples were constructed by using mortar made from (TW) have higher resistance to splitting tensile than the samples constructed by using mortar made from (STWW) in case of line load orientated at 45° from the bed joints.And the comparison between stress for masonry prisms constructed by using mortar made from (TW and STWW) under in-plan tensile strength test at θ = 45 shown at Figure 16. In the case of In-Plane strength of masonry walls, no harmful effects have been detected after 28 days. However, using secondary treated wastewater (STWW) 13 percent of reduction has been observed.

a. Prism constructed using mortar TW. b. Prism constructed using mortar STWW.

Fig. 15: Failure mode of prisms under in-plan splitting tensile test with θ = 45°

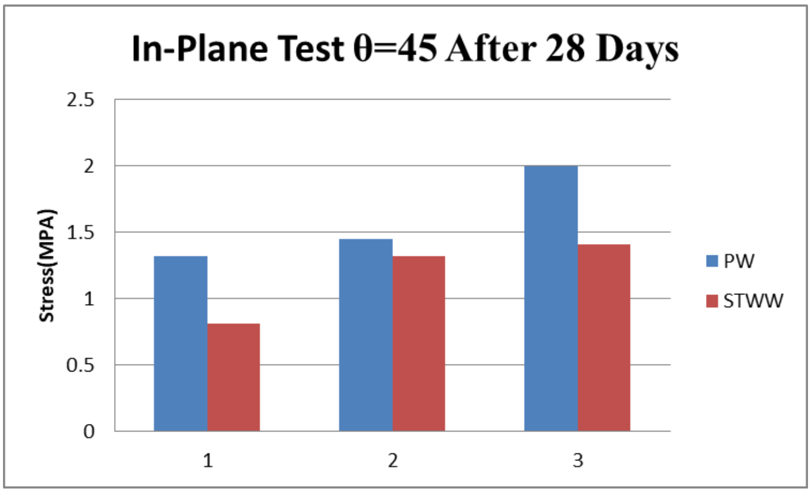


Fig.15: Comparison between stress for masonry prisms constructed by using mortar made from (PW and STWW) under in-plan tensile strength test at θ = 45.

Flexural tensile strength (Out of Plane)

Flexural tension strength normal to bed joints

The Cracks started along the bed joints. For flexural tension normal to the bed joints, failure consists of connecting of the mortar from the unit along the bed joint as shown in Figure 16. The failure cracks in the assemblages were constructed by using mortar made from (TW) occurred at loads (3.0 , 2.9 and 2.9) kN respectively, while the failure cracks occurred in the assemblages were constructed by using mortar made from (STWW) at loads (3.75, 2.15 and 2.30) kN respectively, because the cracking load affected by the strength of mortar.and the average flexural tensile strength in this case of loading of the prisms were constructed by using mortar made from (TW) and mortar made from (STWW) was (0.20 and 0.20) N/mm^2 respectively. The results shows that masonry walls made with secondary treated wastewater have out of plane strength (normal to bed joint) equal of the strength of reference specimens made with tap water.

a. Prism constructed using mortar TW. b. Prism constructed using mortar STWW.

Fig. 16: Failure mode of prisms - out of plane bending tension normal to bed joints.

Flexural tension parallel to bed joints

The cracks started along the head joints and then passing through the bed joints. Cracking in a toothed pattern along a combination of head and bed Joints. For masonry with relatively strong units and weak mortar joints, flexural failure for tension parallel to the bed joints can occur through a combination of tensile and shear connecting in the head and bed joints. Failure cracks in the assemblages were constructed by using mortar with (TW) occurred at loads (1.90, 1.30 and 1.0) kN respectively, while failure cracks occurred in the assemblages were constructed by using mortar with (STWW) at loads (1.0, 1.30 and 1.20) kN respectively as shown in Figure17, and the average flexural tensile strength in this case of load of prism were constructed by using mortar made from (TW) and mortar made from (STWW)was (0.51 and 0.56) N/mm^2 respectively. The out of plane strength test (parallel to bed joint) for tap water as 0.66 and for treated wastewater as 0.56 hence there is a very small amount of difference in strength capacity in between tap water and treated wastewater.

a. Prism constructed using mortar TW.

b. Prism constructed using mortar STWW.

Fig. 17: Failure mode of out of plane bending-tension parallel to bed joints.

IV. CONCLUSIONS

These preliminary research findings suggested that significant difference do not exist between masonry walls made of potable water versus secondary wastewater treatment plant water. The following conclusions on the effect of mixing water on the properties of cement mortar are drawn from the experimental study presented in this chapter.

1. The type of mixing water affected both initial and final setting times. Final setting times were found to increase with secondary treated wastewater.
2. In general, cement mortar made with secondary treated wastewater showed same strength for ages up to 28 days. At early cement, mortar ages of 1, 3, and 7 days, the strength of cement mortar made with secondary treated wastewater was higher than that of cement mortar made with tap water.
3. Secondary treated wastewater, of the type produced from wastewater treatment plants in Egypt, is suitable for mixing cement mortar. The fresh cement mortar properties, strength characteristics and setting times for cement mortar made with secondary treated wastewater, were all similar to those produced using tap water.
4. There was no significant difference in axial compressive strength of masonry prisms between masonry prisms made of potable water versus secondary wastewater plant.
5. It may be concluded from this research that the use of treated wastewater produced from secondary wastewater treatment plant water has negligible effect on the shear strength of masonry walls.
6. The shear strengths obtained for masonry walls made with tap water or secondary treated wastewater are equal 0.3 N/mm^2.
7. In the case of In-Plane strength of masonry walls, no harmful effects have been detected after 28 days. However, using secondary treated wastewater 13 percent of reduction has been observed.
8. The results shows that masonry walls made with secondary treated wastewater have Out of Plane strength (normal to bed joint) equal of the strength of reference specimens made with tap water.
9. The Out of Plane strength test (parallel to bed joint) for tap water as 0.66 and for treated wastewater as 0.56 hence there is a very small amount of difference in strength capacity in between tap water and treated wastewater.
10. In all specimens, the flexural tensile strength values parallel to bed joints are accordance with previous knowledge, significantly greater than that perpendicular to the bed joints.

Some of the possible outcomes and contributions of this research are: to minimize the need for the use of tap water, eliminate the need to expand tap water supply for use in the construction industry, minimize the need to construct more water treatment facilities due to population growth, save tap water for drinking purposes, make wastewater treatment plants become more economically attractive by reusing water before its final treatment, and , other similar goals towards sustainable developments. However, the study should be extended to investigate the effect of wastewater on the durability of masonry walls, since it may contain harmful substances that may affect adversely the cement mortar after prolonged exposure times.

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